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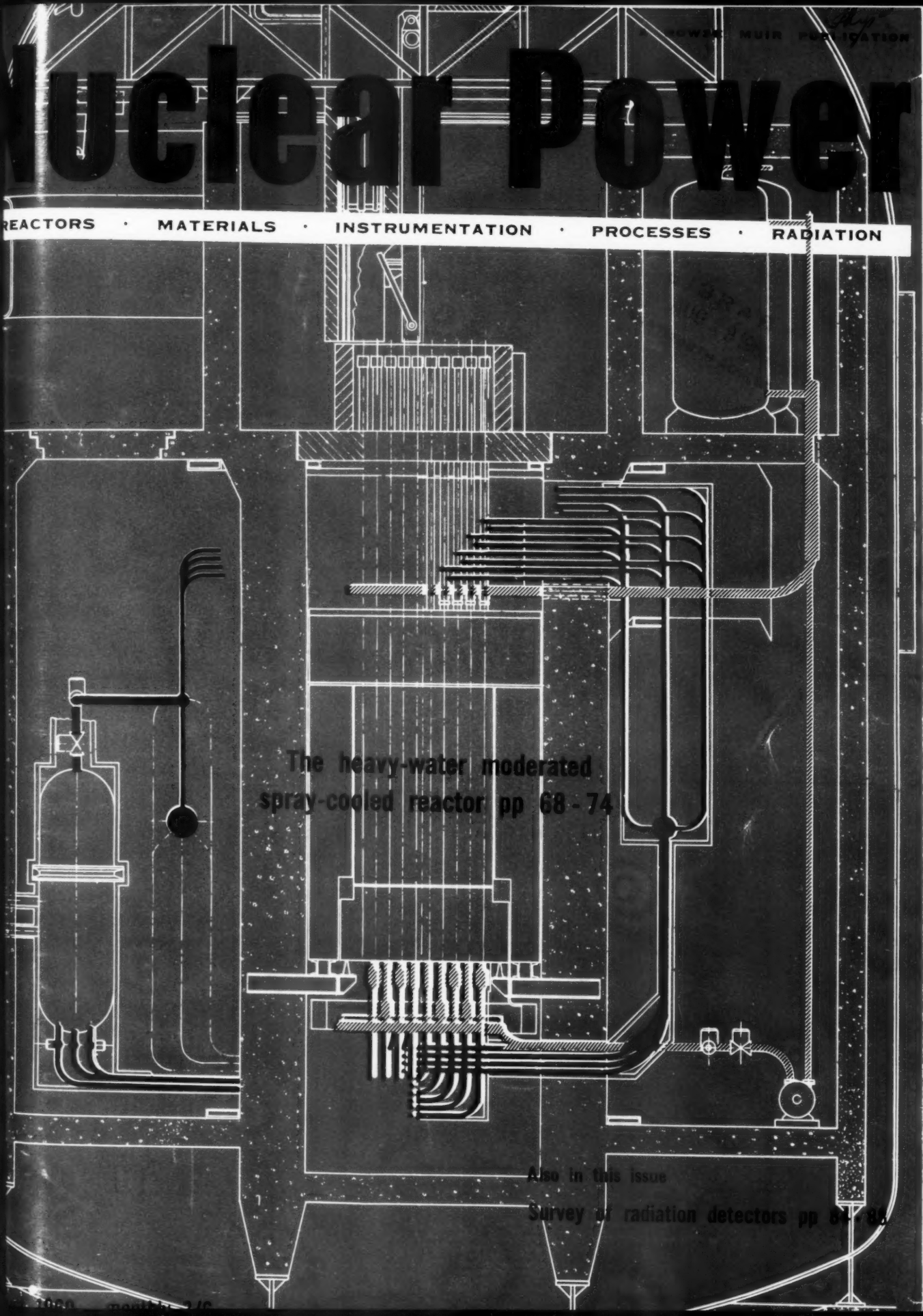

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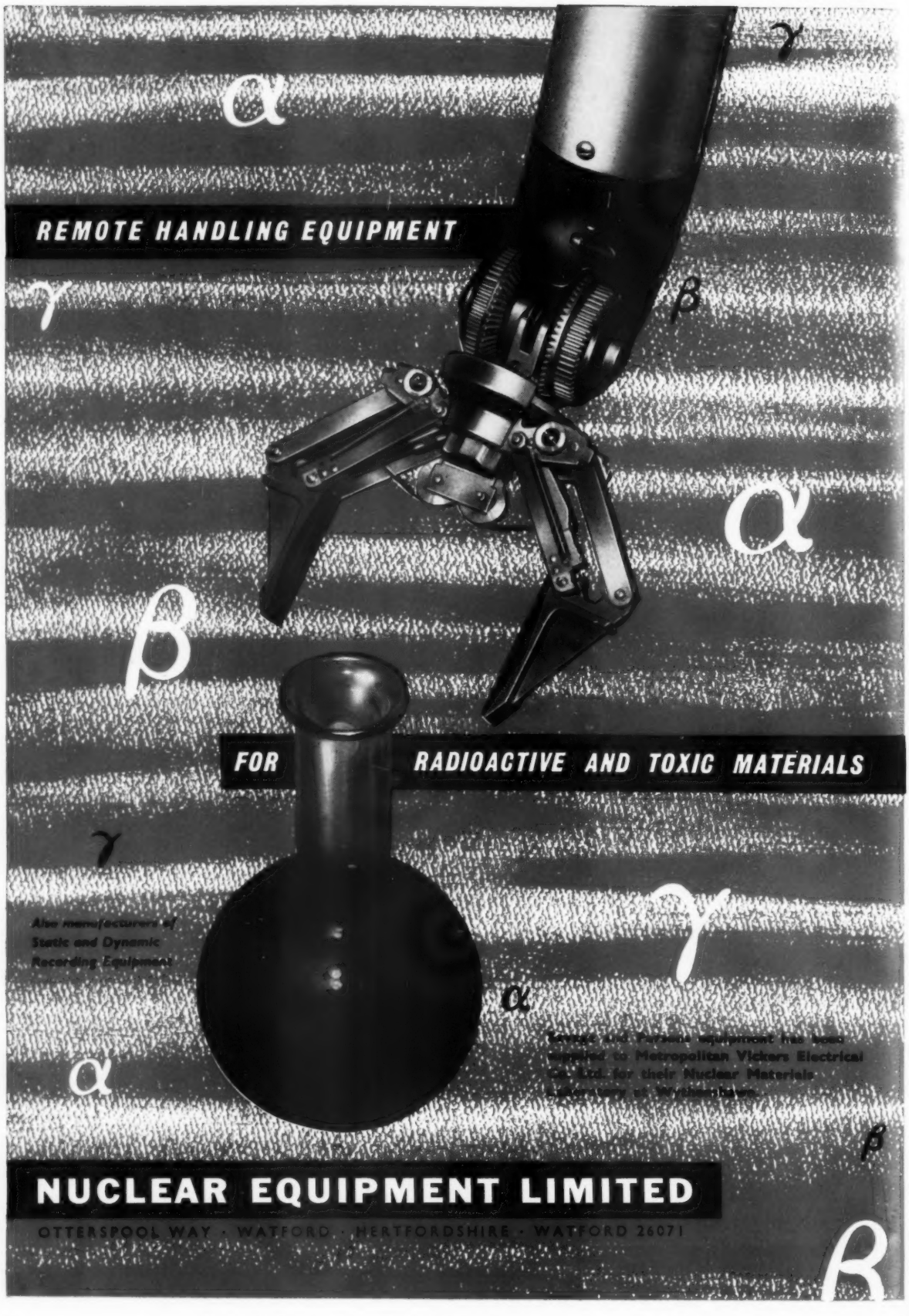
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VOL 5 NO 52 AUGUST 1960

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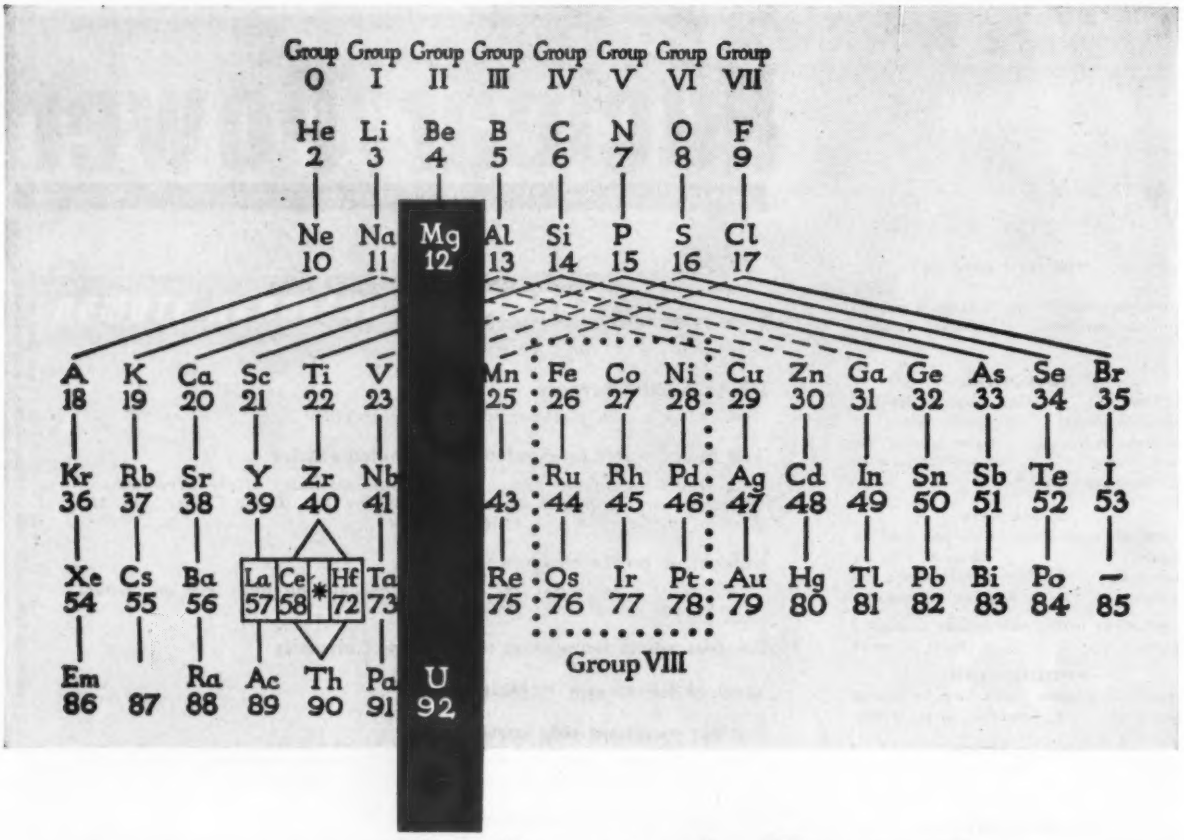

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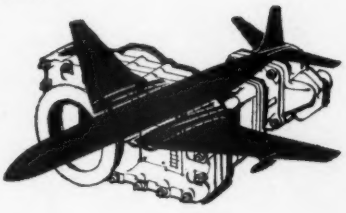

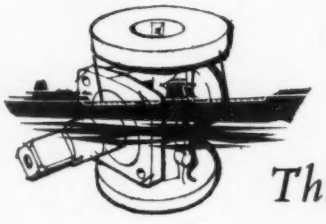

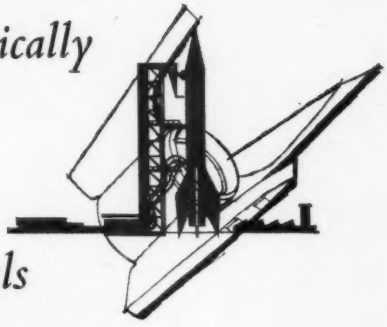

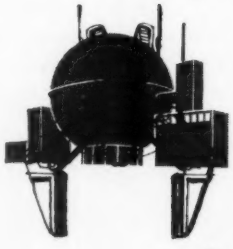

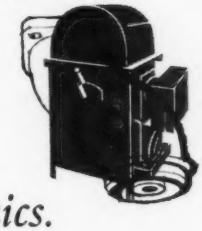

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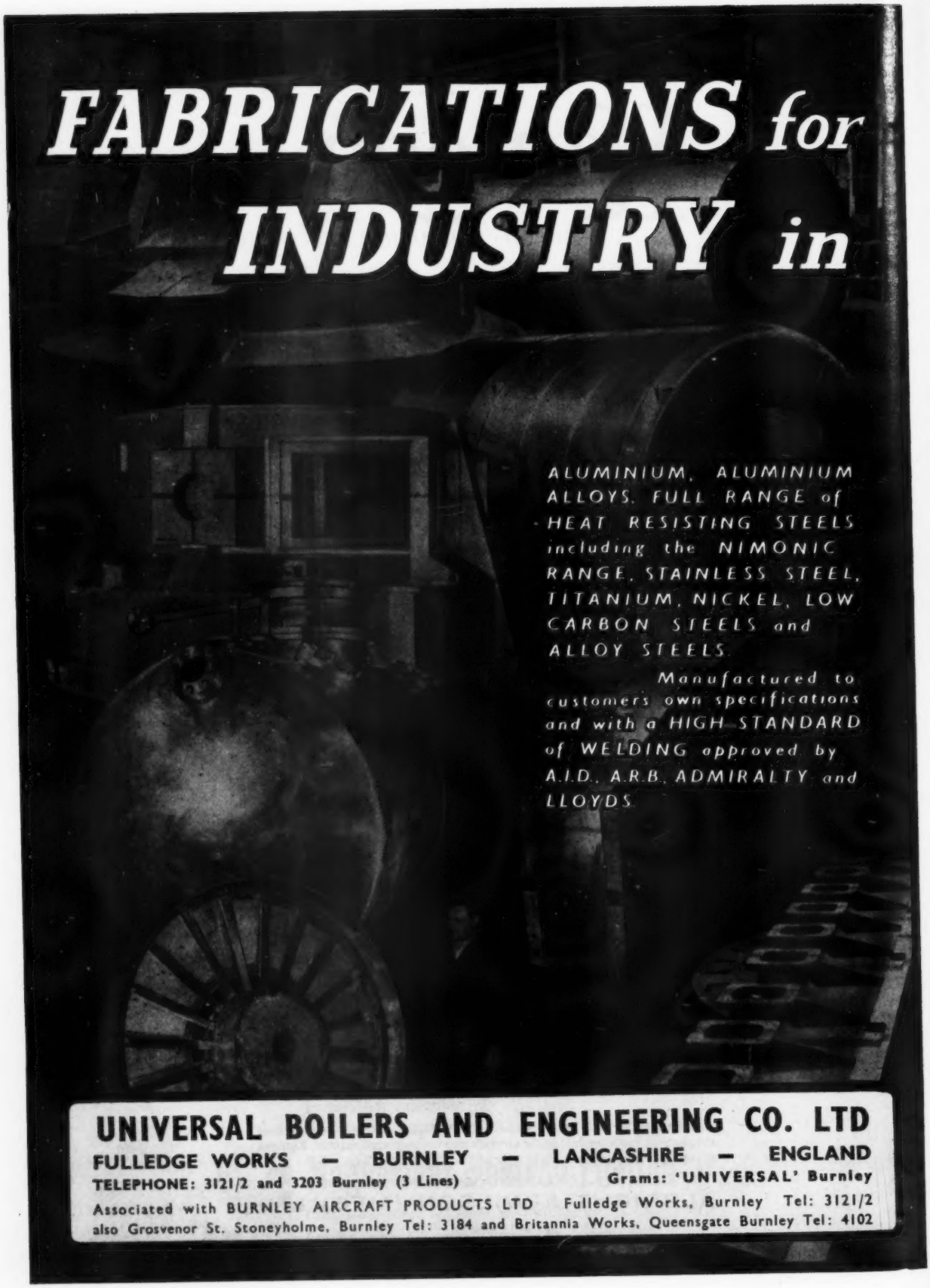
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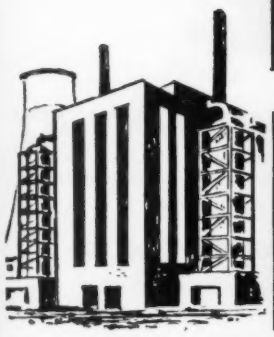

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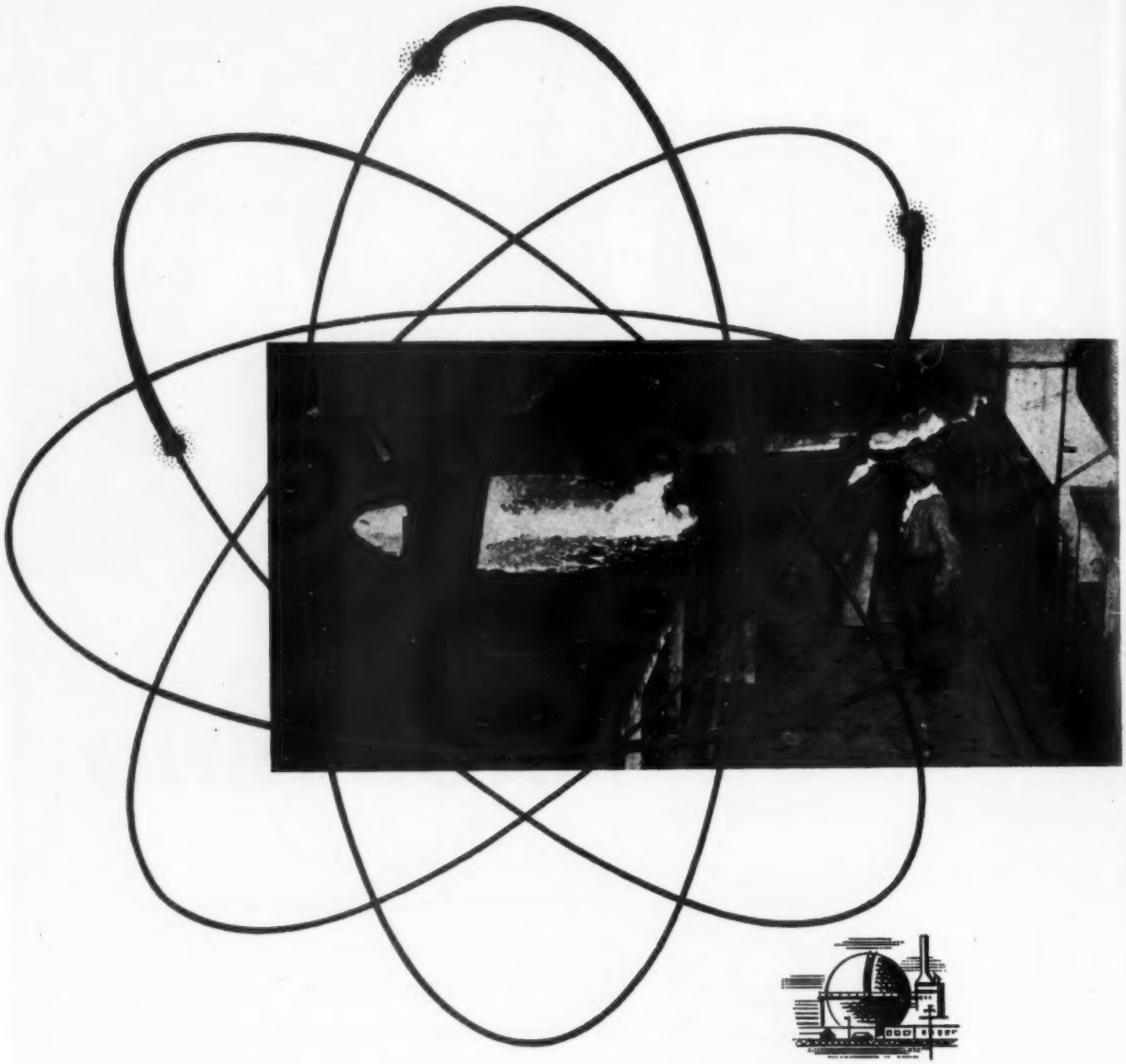

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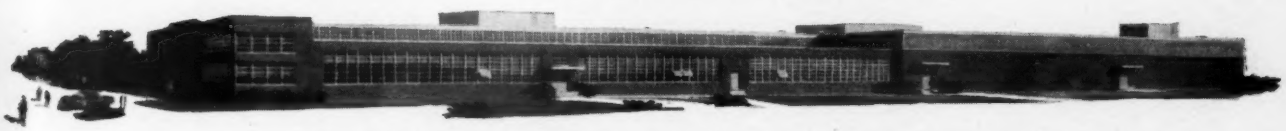

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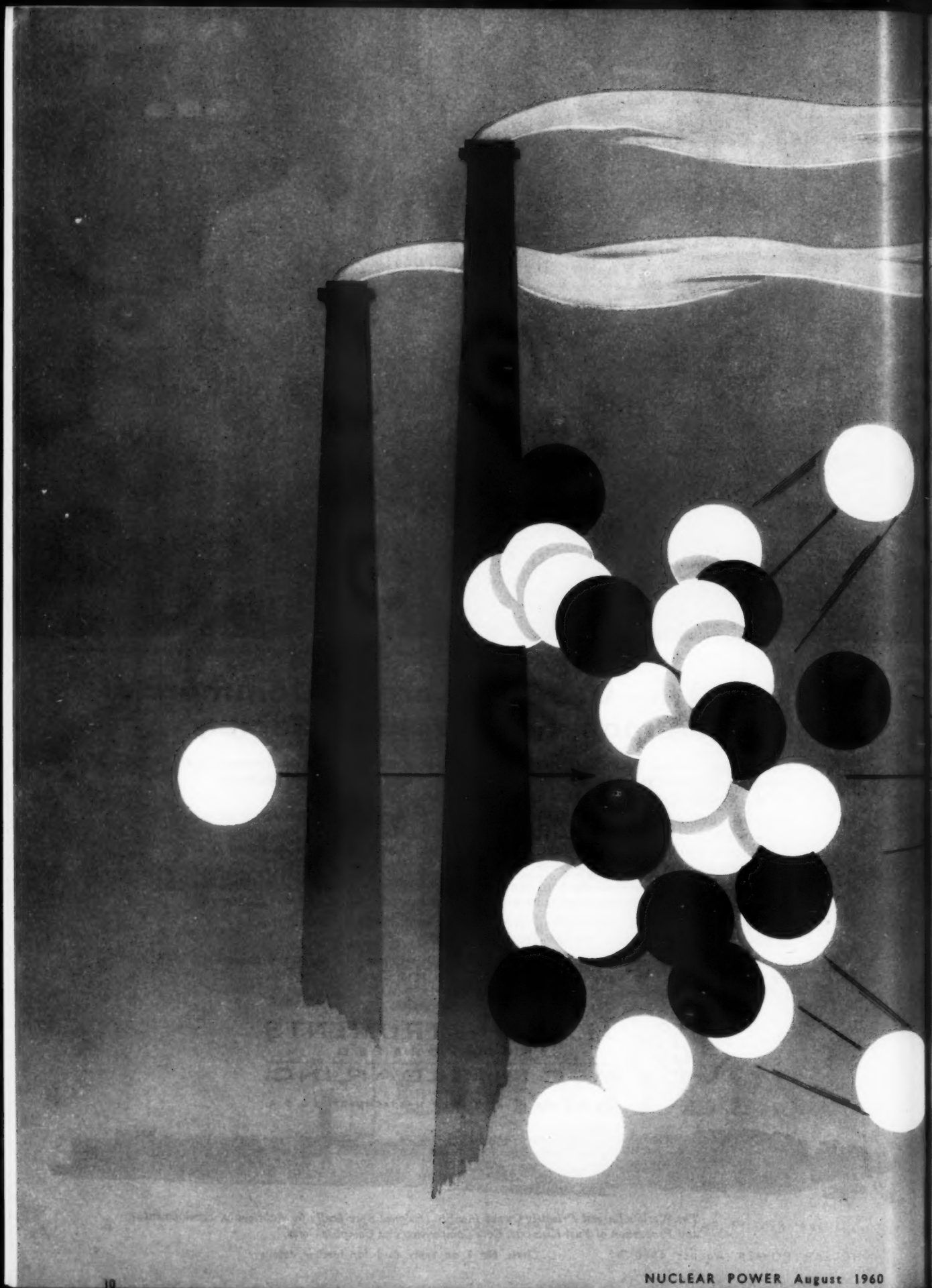

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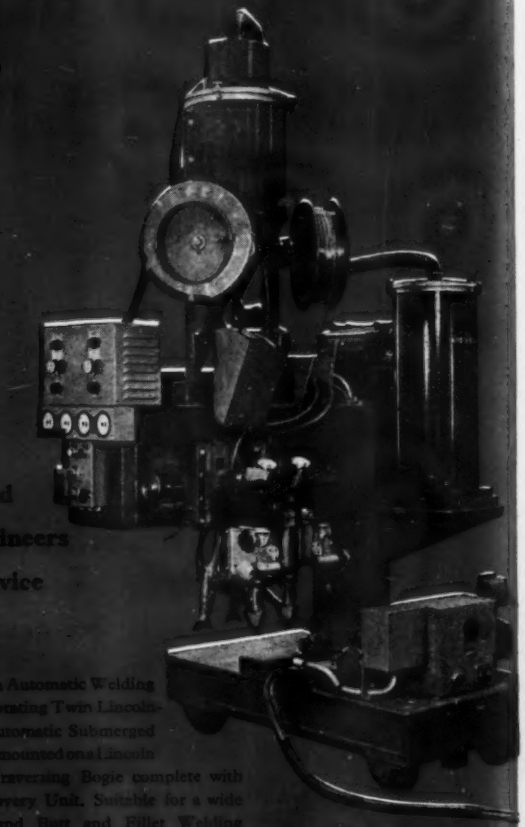

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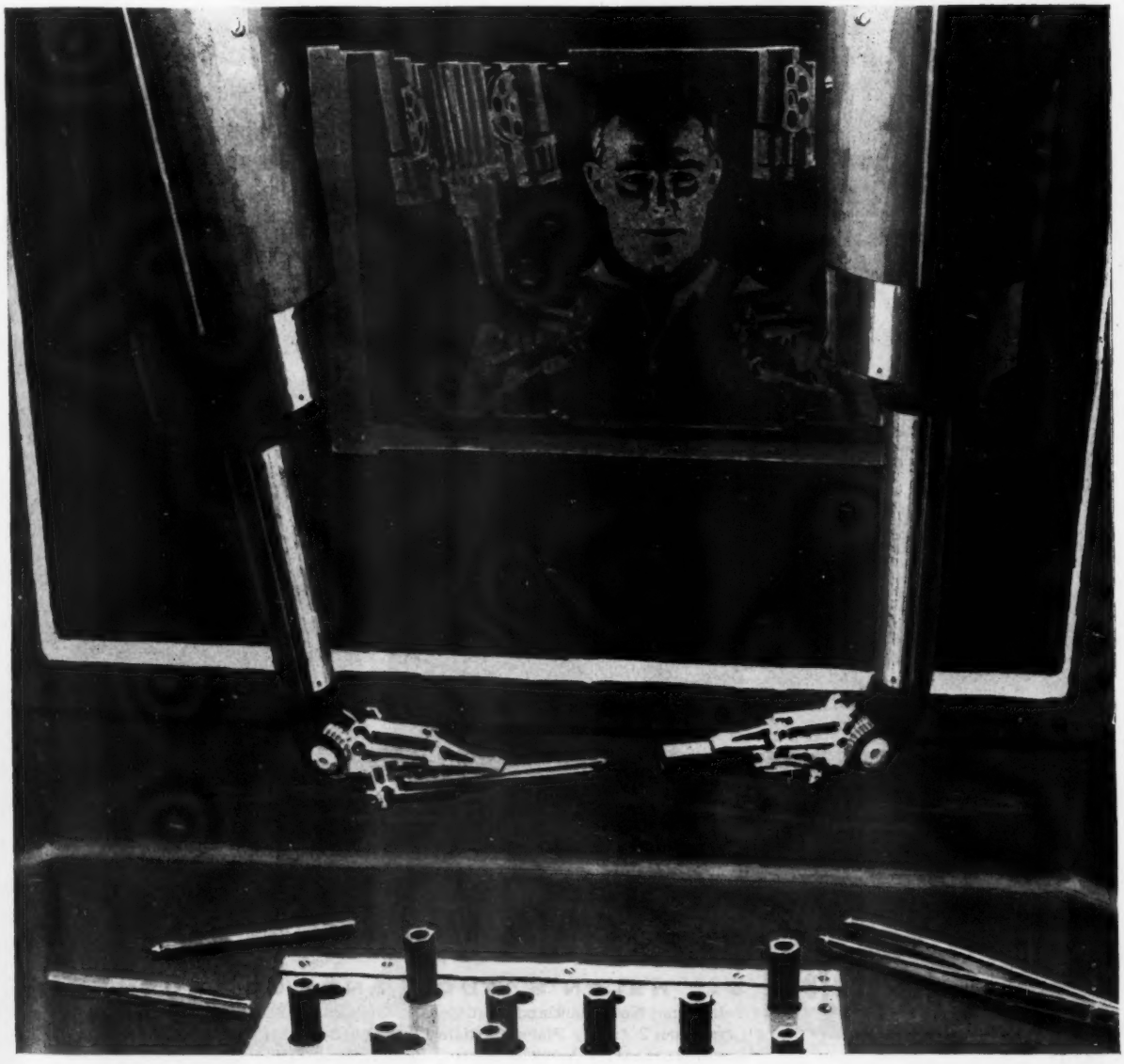

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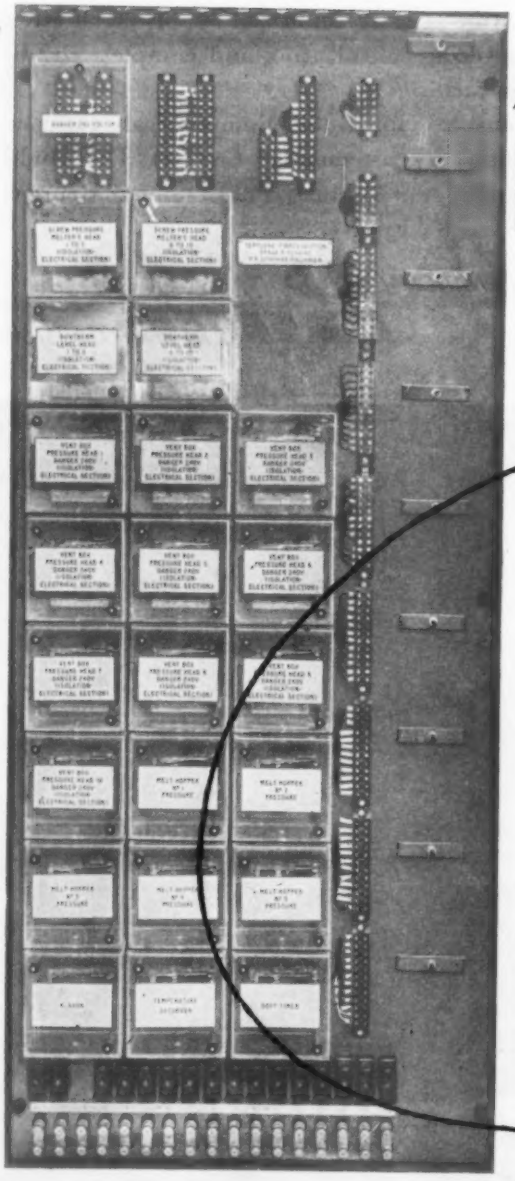

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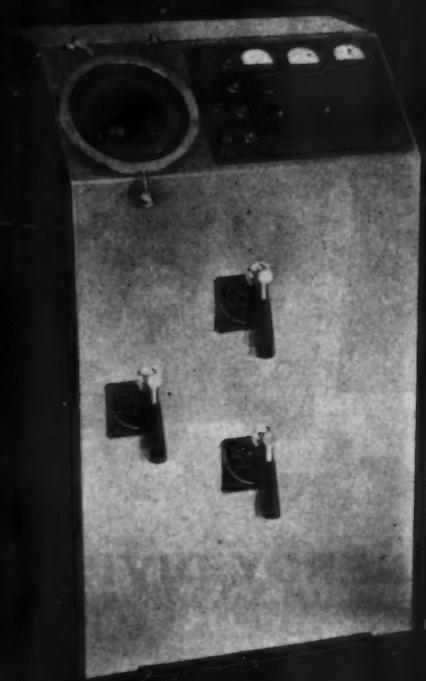

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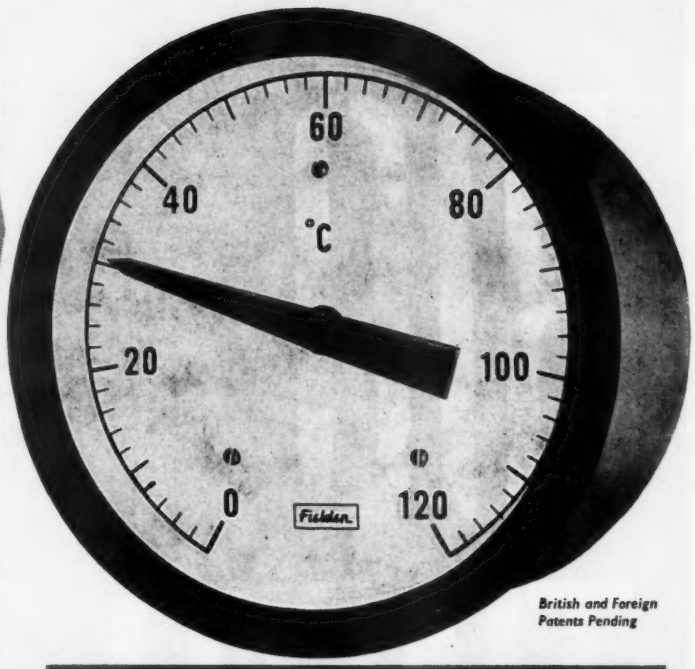

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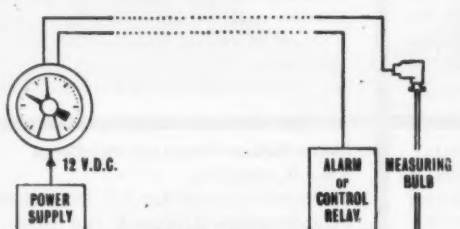

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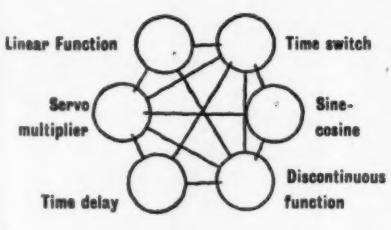

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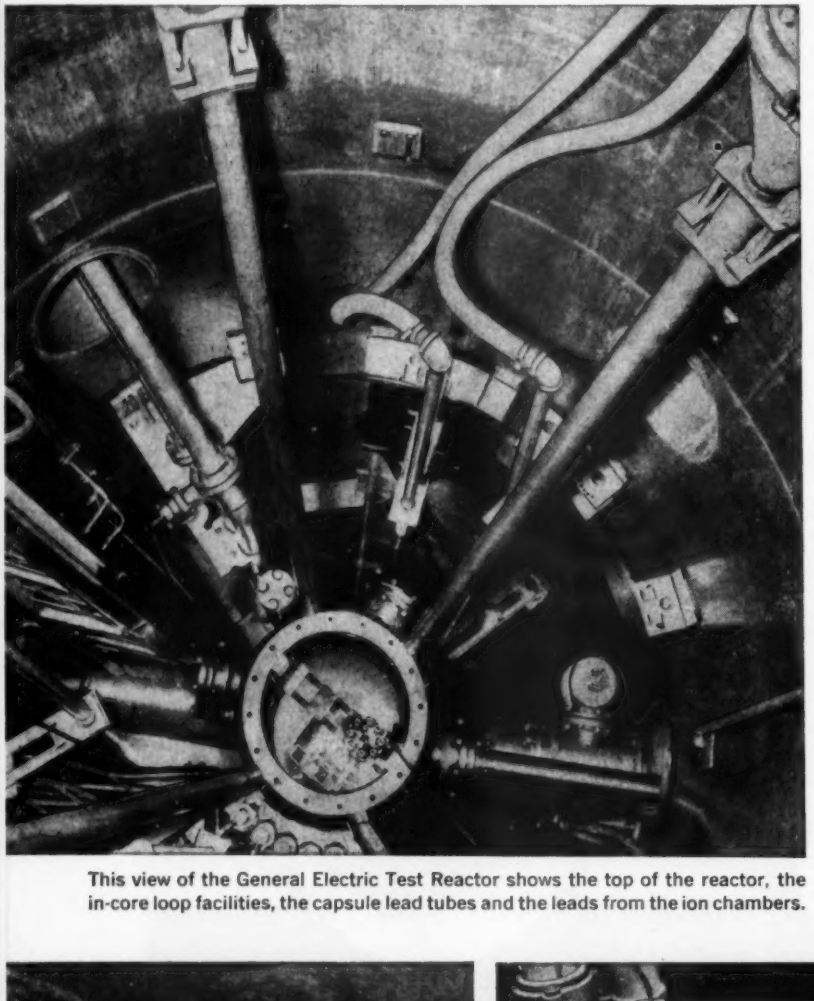
General Electric Invites You To Check These Pages For Facts About Irradiation Services And Reliable Nuclear Components



This view of the General Electric Test Reactor shows the top of the reactor, the in-core loop facilities, the capsule lead tubes and the leads from the ion chambers.

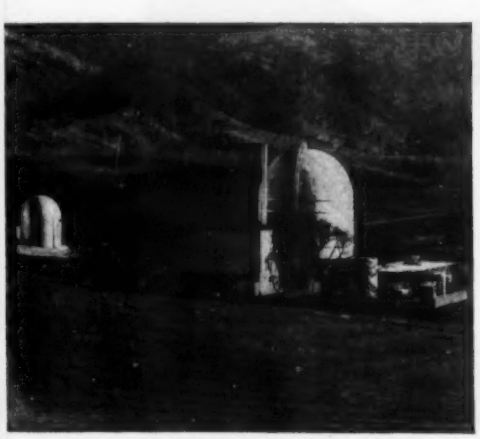
The G-E Test Reactor, a variety of technical services and years of nuclear experience are all important parts of General Electric's complete irradiation services in San Jose and Vallecitos

General Electric's complete nuclear research facilities in San Jose and Vallecitos, California can provide integrated irradiation research and development services which range from basic and applied nuclear research programs to specific testing and development operations requiring specialized experience and equipment. They are available to private industry and governments throughout the free world.

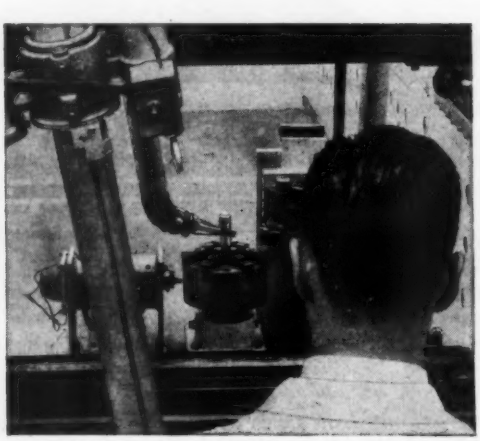
G.E. is staffed and equipped to handle complete research programs from design, procurement and preparation of assemblies for irradiation; through irradiation in the General Electric Test Reactor (GETR); to post-irradiation examination and testing including analysis and reporting. A variety of other technical services are available to meet specialized customer requirements.

Fuel development programs and irradiation studies on materials and components for the advancement of reactor technology can be obtained without the expense of building a reactor.

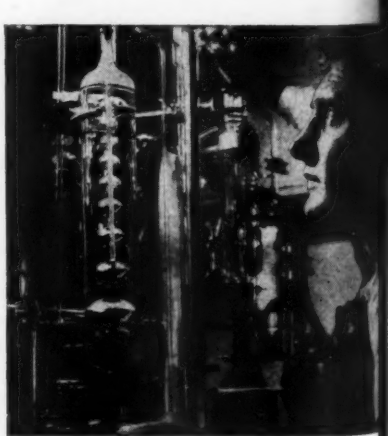
For more information about how General Electric can handle your irradiation research — from start to finish — write for the free bulletin GEA-6934.



This is the 30,000 thermal kilowatt test reactor built and operated by General Electric. It is designed for irradiation testing of fuels, and other materials.



The G-E hot cell lathe station remotely performs cutting and turning on irradiated materials. A large part of the laboratory is devoted to test cells and supporting operations.



G.E.'s technical services include this nuclear chemistry laboratory, a metallurgy and ceramics lab, a physics lab, a nuclear critical assembly, the GETR and other services.

General Electric experience and dependability are built into every Nuclear Reactor Control Rod Drive

General Electric has developed, designed and built more than 25 types of control rod drive mechanisms for boiling water, pressurized water and sodium cooled nuclear reactors. You are assured of more dependability and greater versatility because of this unmatched experience and these 7 important features:

❶ **Reliable Operation and Easy Maintenance.** G-E drives utilize familiar industrial components so spare parts are not a problem. Moving parts are readily accessible, easy to assemble and maintain.

❷ **Dependable Performance by Thorough Testing.** Control rod drive components have been completely tested and proven in service in operating nuclear reactors.

❸ **Versatile Designs For Every Application.** Combinations of components can be varied to meet requirements for speed, stroke, coast, mounting location, etc. Compact arrangement of G-E drives allows mounting on close centers, providing more effective control and flexibility in core design.

❹ **Accurate Position Indication.** G-E control rod drives can be equipped with various types of position indication systems.

❺ **Quick Delivery Of G-E Standard Drives.** The variety of proven drives designed to meet most application needs save costly design and testing time.

❻ **Automatic Control Available.** G-E drives are designed for automatic control. Complete servo systems and components are available.

❼ **Extensive Test Facilities.** Facilities are available for customers who wish to make additional design tests on control rod drives for use on their own reactors.

For complete information of General Electric's performance-proven line of nuclear reactor control rod drives, send for the free bulletin GEA-6609.

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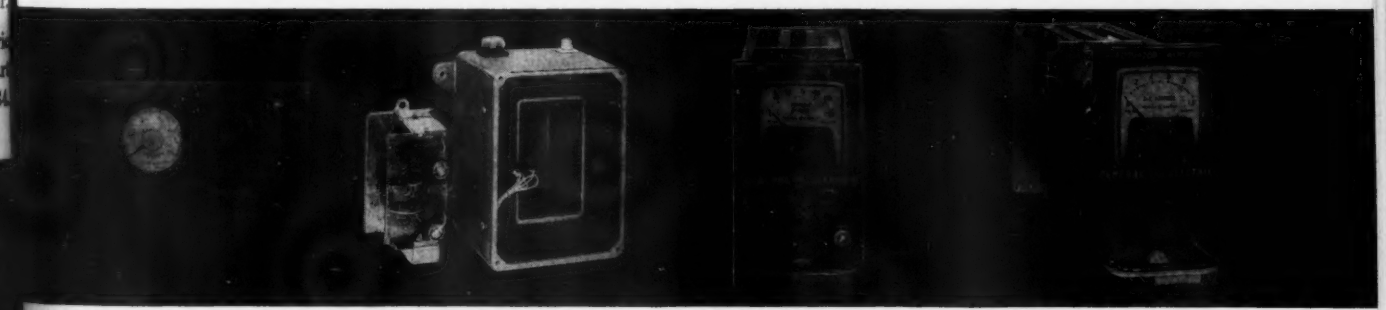
STABLE MICROMICROAMMETER features fast response and very low zero drift.

HIGH-VOLTAGE POWER SUPPLY—a precision instrument for primary nuclear detectors.

LOG-N PERIOD AMPLIFIER provides accurate neutron flux measurement.

LOG COUNT RATE METER WITH PERIOD gives optimum reactor startup protection.



LINEAR COUNT RATE METER provides direct indication of nuclear pulses.

PREAMPLIFER is a small amplifier for fission or proportional counter pulses.

FLUX AMPLIFIER—for reliable continuous self-testing and automatic substitution.

ACTUATOR AMPLIFIER supplies and controls current to safety magnets to shut down reactor.

Send for free bulletin GEA-7006 on nuclear instruments and system design services.

General Electric leads the way to greater progress in the nuclear field, whether it's for irradiation services, nuclear components or a complete power reactor such as the 180,000 kw Dresden Power Station now in operation near Chicago. For the free bulletins listed above, or for further information about nuclear equipment to meet your needs, write: *International General Electric Co., Dept. 30-11, 150 East 42nd Street, New York 17, N.Y., U.S.A.*

GENERAL ELECTRIC

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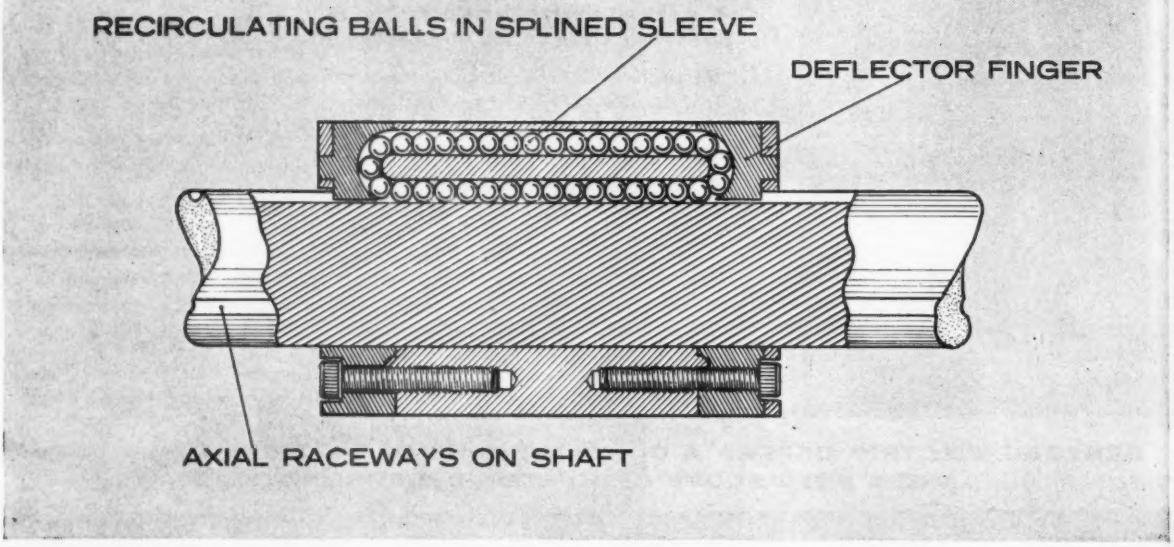
Circle **No 19** on reply card for further details

Beaver ball splines, over 90% efficient, operate at -55° C to 450° C and over . . .



. . . ANOTHER ENGINEERING ADVANCE FROM BRISTOL SIDDELEY

Bristol Siddeley Engines Limited produce Beaver* ball splines. These ball splines achieve a minimum efficiency of 90% and they can operate within a temperature range of −55° C to over 450° C.

Machined and ground to the highest standards of precision, Beaver ball splines are much more efficient in operation than conventional splines. They substitute a recirculating stream of precision-ground balls, rolling along specially contoured grooves, for the solid key and keyway. This arrangement reduces friction to a minimum when the spline assembly is subjected to linear, torque and bending loads. It also gives optimum smoothness and a very fine degree of positioning accuracy. When compared to conventional spline mechanisms, Beaver ball splines require a much smaller power source; provide a predictable operating life; need much less maintenance; and give long trouble-free operation.

Basic design application analysis

Bristol Siddeley engineers make an exhaustive analysis of each specification and each unit is specially designed for its particular application. For Beaver splines can be made with angular pre-loading, with multiple circuits, and with telescopic extensions. Beaver splines have been proved as the most efficient method of minimising friction when high torsional and bending loads are imposed during linear movement in many engineering applications. They have been designed already with rated operating torque capacities of 50,000 lb/in (200,000 lb/in maximum static torque) but the maximum potential operating torque is, in most cases, limited only by the requirement.

Bristol Siddeley Beaver ball screws reduce the power required for actuation by as much as 80%. By eliminating backlash, with pre-loading, they give precise control over very small increments of motion when converting rotary drive into linear output.

**Complete technical and manufacturing co-operation with Beaver Precision Products Inc, Detroit.*

For further information please write to J. B. Starky, Sales Manager, (Beaver Products Division), Bristol Siddeley Engines Limited, PO Box 17, Coventry, England.

BRISTOL SIDDELEY ENGINES LIMITED

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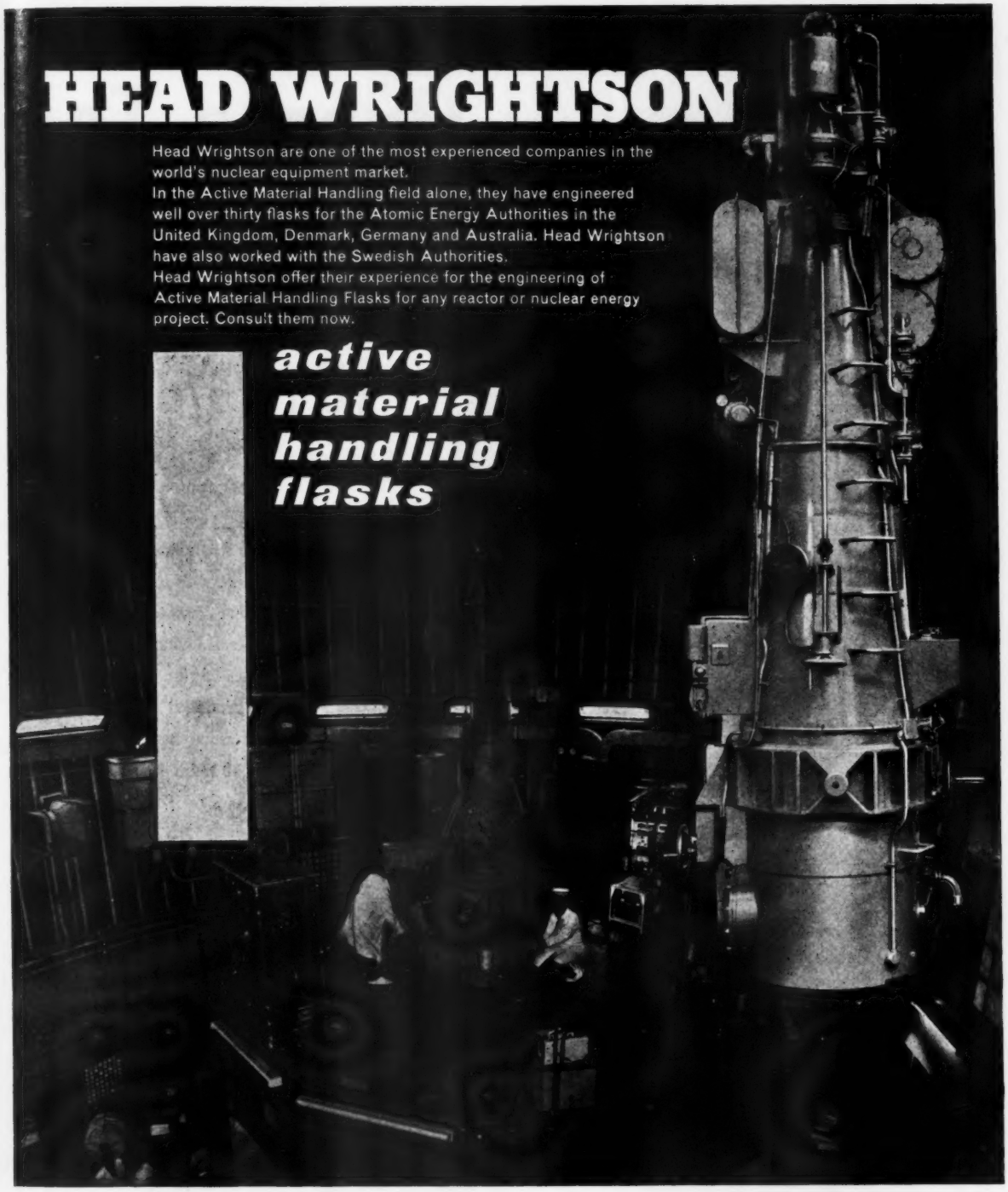
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P5166

Over a Ton

of Aluminium Alloy spun to 10 ft. i/d x $1\frac{5}{8}$"

One of a number produced for pressure vessels to hold liquid air, this 10 ft. aluminium end was spun by Harveys on the Rotarpress. The 12 ft. flat discs needed for spinning these ends, which are believed to be the largest spun aluminium ends produced in this country, were formed by butt-welding two plates of aluminium alloy together.

The Rotarpress is one of the large-capacity units in Harveys Heavy Fabrication Department. It produces ends up to 15 ft. diameter and is adaptable over a wide range of knuckle radii and depths.

The contours of semi-ellipsoidal ends produced by the spinning process enable plate thickness to be reduced, and in most cases tool costs are eliminated. Enquiries are invited for ends only or for complete

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Exceptional cold strength at 24 hours and permanent residual strength for structural purposes at elevated temperatures.

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Shielding action at elevated temperatures due to high proportion of combined water.

(*Temperature limit up to 1350°C, dependent on type of heat-resistant aggregate employed !)

Our Technical Dept. is entirely at your disposal for further specific information

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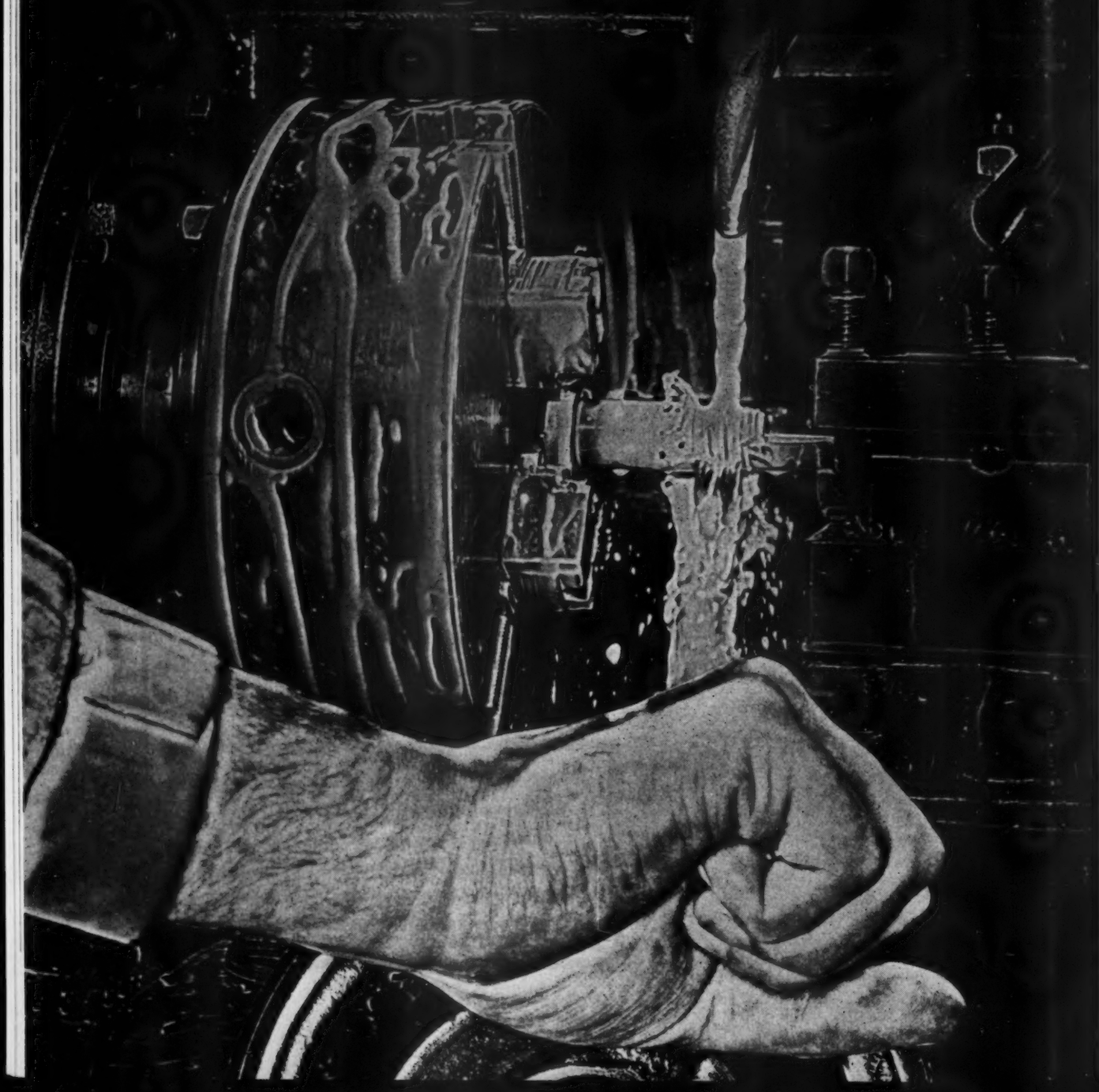
For operating temperatures up to 1800°C, or when a refractory resistant to reducing conditions is required, use Super-Duty Refractory Concretes made with SECAR 250, a pure white calcium-aluminate cement, free from iron oxides. Write for details.

AP122

Greater safety for hands



With new Shell Dromus Oils

Most modern soluble cutting oils contain phenolic compounds used as coupling agents between the oil and the emulsifier, for better blending and easier mixing. These phenolic compounds can cause skin irritation, especially where modern high-speed machines are used and the emulsion can concentrate, through the evaporation of water, above the safety level.

Shell research chemists have been working on this problem, which has been causing some concern to Management. After considerable research, Shell Dromus Oils have been reformulated and these new cutting oils now produce bland emulsions, which considerably reduce the risk of skin trouble to operators.

The real difficulty was to find a new coupling agent to replace the phenolic compounds, and Shell finally used what their chemists know as a higher fatty alcohol complex. This solved one problem, but presented another. The new coupling agent was volatile at the high temperatures normally used in blending processes. Further research found a solution to this problem by designing and installing new plant.

The new Dromus Oils are every bit as efficient as before and cost no more. They put Management in the welcome position of being able to minimise working hazards at no extra cost. And machine men need no longer be so worried about skin troubles.

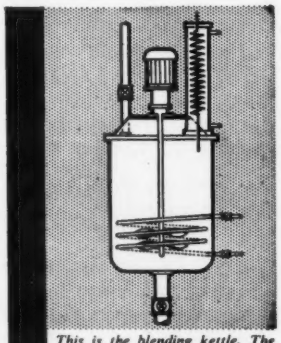
The moral of the story is that Shell research is supremely applicational. The centre at Thornton is always ready to work with even the most specialised sectors of industry to produce the right oil for the job. If you and your organization have any major lubricating problems, it pays to get in touch with your local supplier of Shell Industrial Lubricants.

The Research Story

Shell chemists in the U.K., in Holland and in the U.S.A., prepared and examined hundreds of experimental soluble oils, and established that certain combinations of fatty alcohols could be used in place of phenolic compounds with no loss of efficiency. They set to work to discover the best combination and developed a higher fatty alcohol complex which fitted exactly. Then they realised that to blend this new coupling agent into soluble oils would require special plant and new blending techniques.

Exhaustive testing of blend stability, emulsion stability, anti-corrosion and machining properties led to selection of the most promising blends. A pilot plant was set up to produce batches of these for use in field trials.

This field testing and final development proceeded for two years whilst production plants were erected at points so chosen as to give the most economical and rapid delivery throughout the United Kingdom.

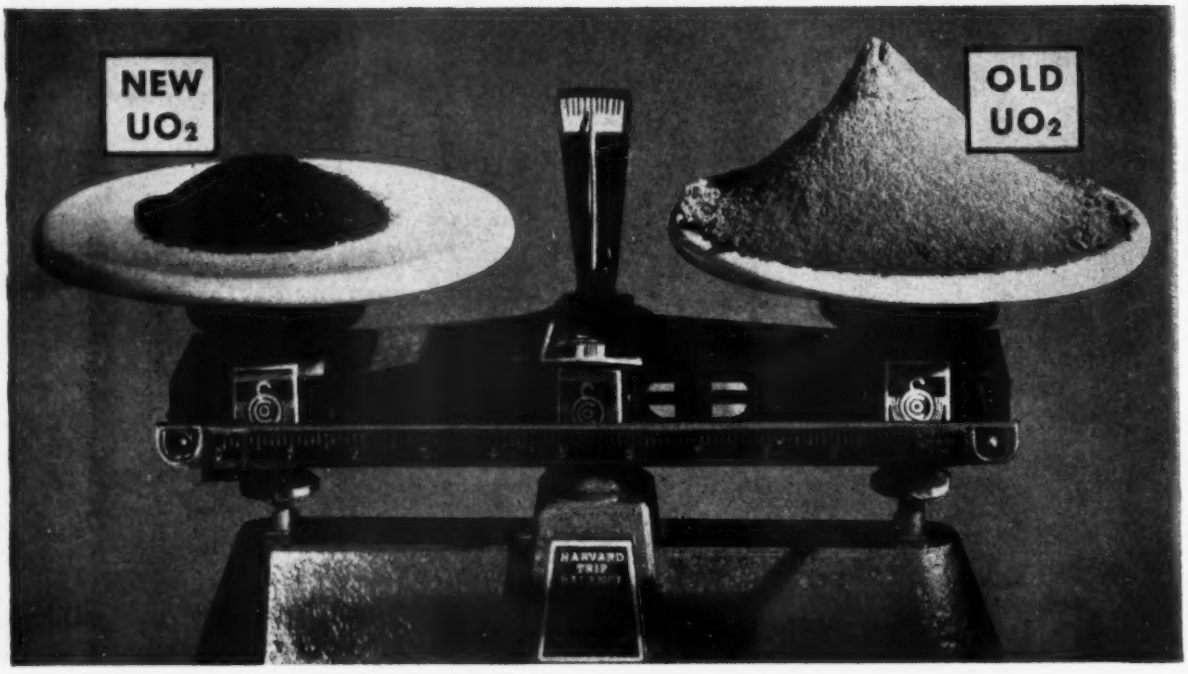


This is the blending kettle. The reflux condenser beside the stirrer motor prevents the loss of constituents volatile at the blending temperature.

NEW SHELL DROMUS SOLUBLE CUTTING OILS

another proof of Shell leadership in lubrication

Circle No 25 on reply card for further details



On this scale are equal weights of Spencer's new fused uranium dioxide (left) and old-type ceramic uranium dioxide. Because of its high density and great purity, Spencer fused UO_2 is considered a major breakthrough in the economical fabrication of fuel element core material.

Spencer Chemical Company Announces New Crystalline Nuclear Fuel Materials

In the ever increasing efforts of American industry to attain economically competitive electrical power from nuclear fuels, considerable attention has been focused upon fuel fabrication costs.

After concentrated research and development in this area, Spencer Chemical Company is proud to announce its new family of crystalline fuel materials that can be fabricated by simple and inexpensive techniques.

The new Spencer fused UO_2 was one of the fuels selected by the Hanford Works of the U. S. AEC, operated by the General Electric Company.

Recently in the United States—United Kingdom exchange of information under the Libby-Cockroft agreement, Hanford reported:

"A 6,000 lb. lot of arc-fused UO_2 was received from Spencer Chemical Company. The material meets our rigid specifications for purity and density. This amounts to a significant break-through in the preparation of fuel element core material. The UO_2 will be fabricated into both swaged and vibrationally compacted PRTR (Plutonium Recycle Test Reactor) fuel rods."

Initial irradiation tests indicate that the quality of the nuclear fuel will increase while the costs of fabrication are lowered.

Crystalline fuel materials currently available are:
Uranium Dioxide (UO_2)
Thorium Dioxide (ThO_2)
Urania-Thoria in solid solution (UO_2-ThO_2)
Triuranium Octoxide (U_3O_8)
Uranium Monocarbide (UC)
Uranium Dicarbide (UC_2)

For more detailed information on Spencer's new crystalline nuclear fuel materials, contact Spencer Nuclear Fuels Department at address below.

SPENCER NUCLEAR FUELS

Produced by

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Spencer Chemical Company

America's Growing Name In Chemicals

General Offices: Dwight Building, Kansas City 5, Missouri, U.S.A.

Gas bearing pumps— totally enclosed, gas lubricated—for liquids up to 700° C, without contamination . . .

. . . ANOTHER ENGINEERING ADVANCE BY BRISTOL SIDDELEY

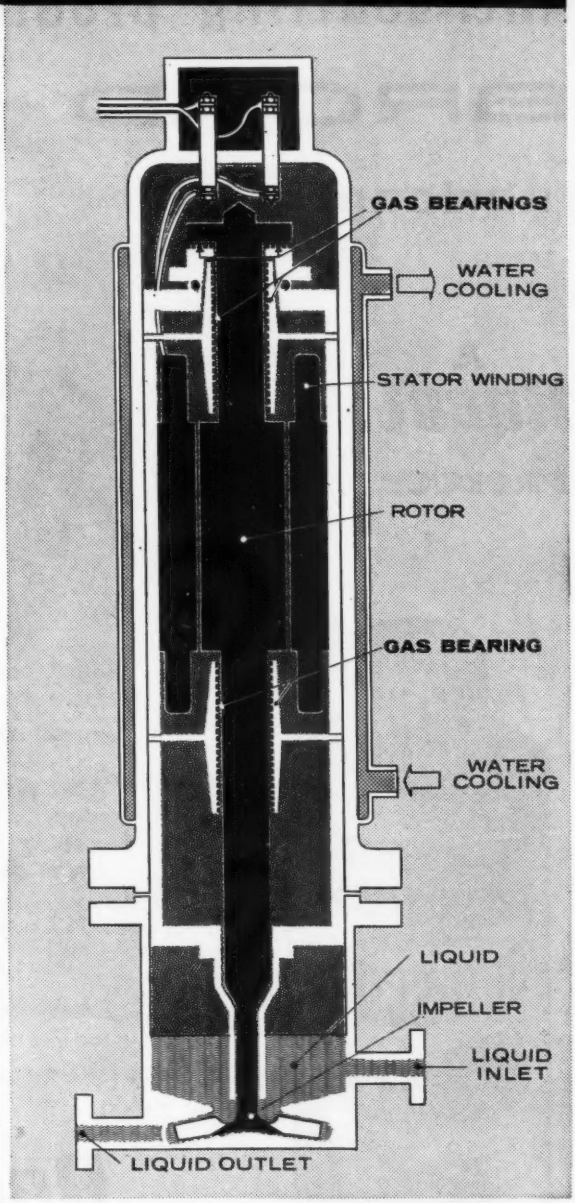
One of the largest manufacturers of motive power units in the world, Bristol Siddeley Engines Limited produce gas bearing pumps. The range covers a wide performance capacity and will pump liquids up to 700° C with a power input from fractional to 30 hp.

Bristol Siddeley gas bearing pumps have been designed specifically for systems where the contamination of liquids by lubricants or the atmosphere cannot be tolerated. Each unit, fitted with self-acting gas bearings, is totally enclosed and no seals are required between the impeller and the bearings.

Gas bearings have several great advantages over oil lubricated bearings: the load-carrying capacity increases with speed, temperature and pressure; the bearings are supported on a film of chemically pure gas contained within the system, so there is no metal-to-metal contact under operating conditions, and wear and maintenance are reduced to an absolute minimum.

Widest experience—greatest range

Bristol Siddeley gas bearings were developed originally to meet the extremely fine limits of operating purity and precision of nuclear engineering. But gas bearings have many other applications where a rotating shaft must be supported in such a way that no contamination and leakage can be allowed and where the supply of chemically pure fluids or gases is essential: in the textile, chemical engineering, pharmaceutical, food storage and processing industries, to name but a few. Bristol Siddeley produce a wider range of gas bearings than any other manufacturer and have the greatest experience in their design and application.



For further information about Bristol Siddeley gas bearing pumps and gas compressors, please write to H. J. Prince, Sales Manager, Reactor Components Division, Bristol Siddeley Engines Limited, PO Box 17 Coventry, England.

BRISTOL SIDDELEY ENGINES LIMITED

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ANTI-SCUFFING OIL. For reinforcement of all lubricating oils.

ANTI-SCUFFING SPRAY. In aerosol form — containing bonding resin.

Our Technical Information Service will provide any further information you may require about these and other Rocol Molybdenised Lubricants.

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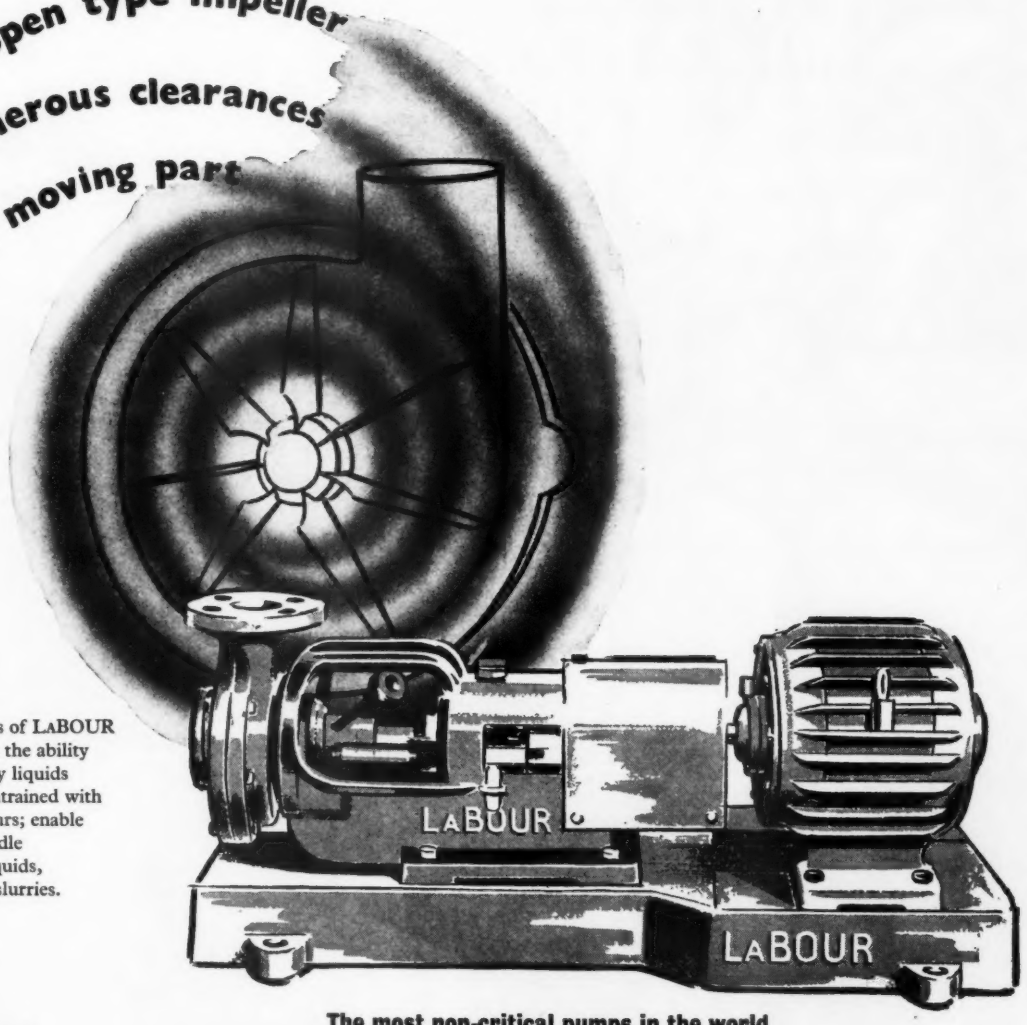

These features of LABOUR pumps ensure the ability to handle dirty liquids and liquids entrained with gases or vapours; enable pumps to handle all types of liquids, effluents and slurries.

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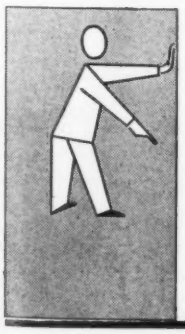

NO CORROSION

LABOUR *originators of the first practical self-priming pump*

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P4319

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What is your climate like?

A recent enquiry (survey would be too grand a word for it) carried out by our editorial department found that an increasing number of readers were subscribing at the reduced Group* rate and taking a personal copy of *Nuclear Power*.

This, from our point of view, is splendid, for above everything we want to be thoroughly read.

But then a snag appeared. Reports from youngish readers frequently mentioned that although home reading was an improvement on snippets snatched from the office circulation copy during lunch, there were certain distractions to be reckoned with.

There is in our experience only one answer to this. One evening should be set firmly aside.

We are not seriously suggesting that Wednesday night should be *Nuclear Power* night. But since up-to-date information is vital to career-building, an occasional strictly-reserved-for-reading session is surely justified.

*For details of the Group rate reduction tick and post the card opposite page 59.

Put NEWTHERM to any test!

NEWTHERM Calcium Silicate insulation manufactured solely by NEWALLS is the most versatile material you can use for application up to 1400°F. Try it. Put a sample section or slab on part of your plant and *prove for yourself* its outstanding ability to withstand impact and water damage.

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Weight - for - weight, NEWTHERM compares favourably with many materials far inferior in thermal efficiency and strength. This light weight is evidenced in the handleability of NEWTHERM, which even in the largest sections can easily be carried in one hand.

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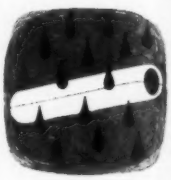
You can immerse NEWTHERM in water and its strength remains largely unimpaired. Nor does it become deformed when in contact with moisture, thus work-in-progress need not be covered. Wherever damp or humid conditions pertain, NEWTHERM is the logical material to use.



STRENGTH

Of major advantage on remote sites, NEWTHERM is unusually strong and rigid, and can withstand rough handling in transit and erection. In the case of vulnerable large-diameter sections, the hard surface offers excellent protection.

EASY APPLICATION

Supplied in pre-formed sections and slabs, NEWTHERM is available in a wide range of standard sizes (and also as plastic). The smooth surface and straight edges permit easy and speedy fitting, with minimum joints and neat finish.

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NEWTHERM calcium silicate insulation

Please ask for your copy of the NEWTHERM booklet. Packed with information on limiting temperatures, thermal conductivity, compressive strength, applicational details, etc., it's a must for your bookshelf. Copies available from sole manufacturers—NEWALLS

A Vital contribution to Atomic Power . . .

"WANDLESIDE"

ARMOURED CABLE

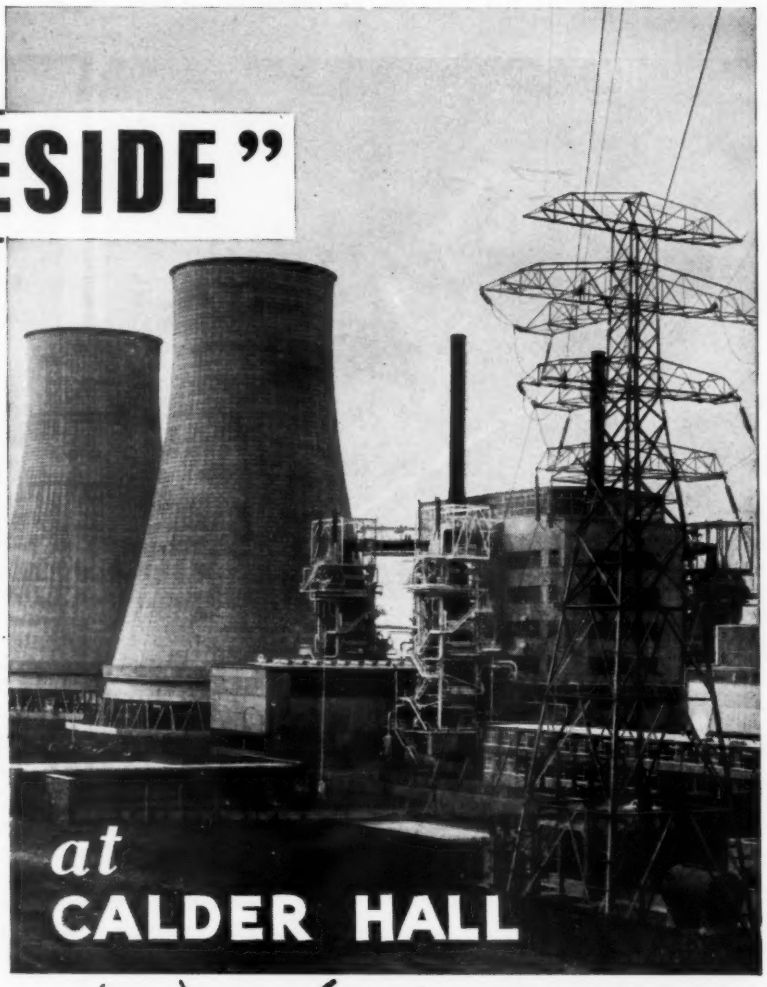

Photo by courtesy U.K. Atomic Energy Authority

With the advancement of Atomic Power, cables must play an important part in the efficiency and reliability in the production of Nuclear Energy. Only the best is good enough and Wandleside Cables are eminently suitable.

WANDLESIDE CABLES *for Nuclear Energy*

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'Pinboard Programming'

new style data processing using Honeywell digital potentiometer

Here's a new Data Processing system for logging and scanning using the Honeywell Digital Potentiometer with a unique feature—Pinboard Programming.

Its Purpose is to give easy operator adjustments whilst it monitors and logs many variables, such as temperature, pressure and speed, to an accuracy of 0·1%.

Drawer-mounted Pinboards do more than save space. They add an easy flexibility to the adjustments of span, zero suppression and alarm limit settings. Only a simple re-positioning of pins is required to change these functions. A comprehensive pinboard programming data system has recently been completed for R.A.E., Farnborough.

Ease of Operation, simple maintenance and continuous checks are built-in advantages of the Honeywell system. It is suitable for research, pilot plants and general industrial use, and may also be used to supply information to computers. Annunciator panels, linearisation circuits and other features are available.

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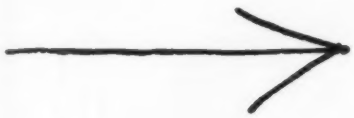
First in Control

SINCE 1885

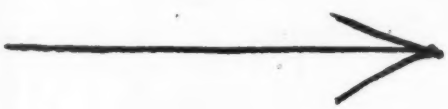
sure shield...

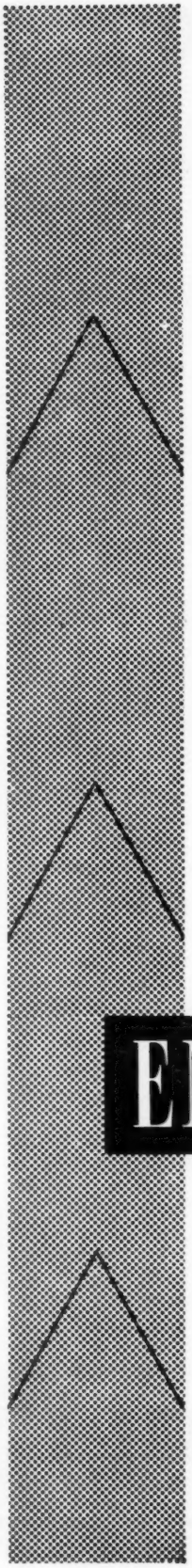
in nuclear engineering



WHY is lead so widely and successfully used as a shielding material for protection against gamma rays?

BECAUSE it can easily be cast or fabricated into complex shapes.





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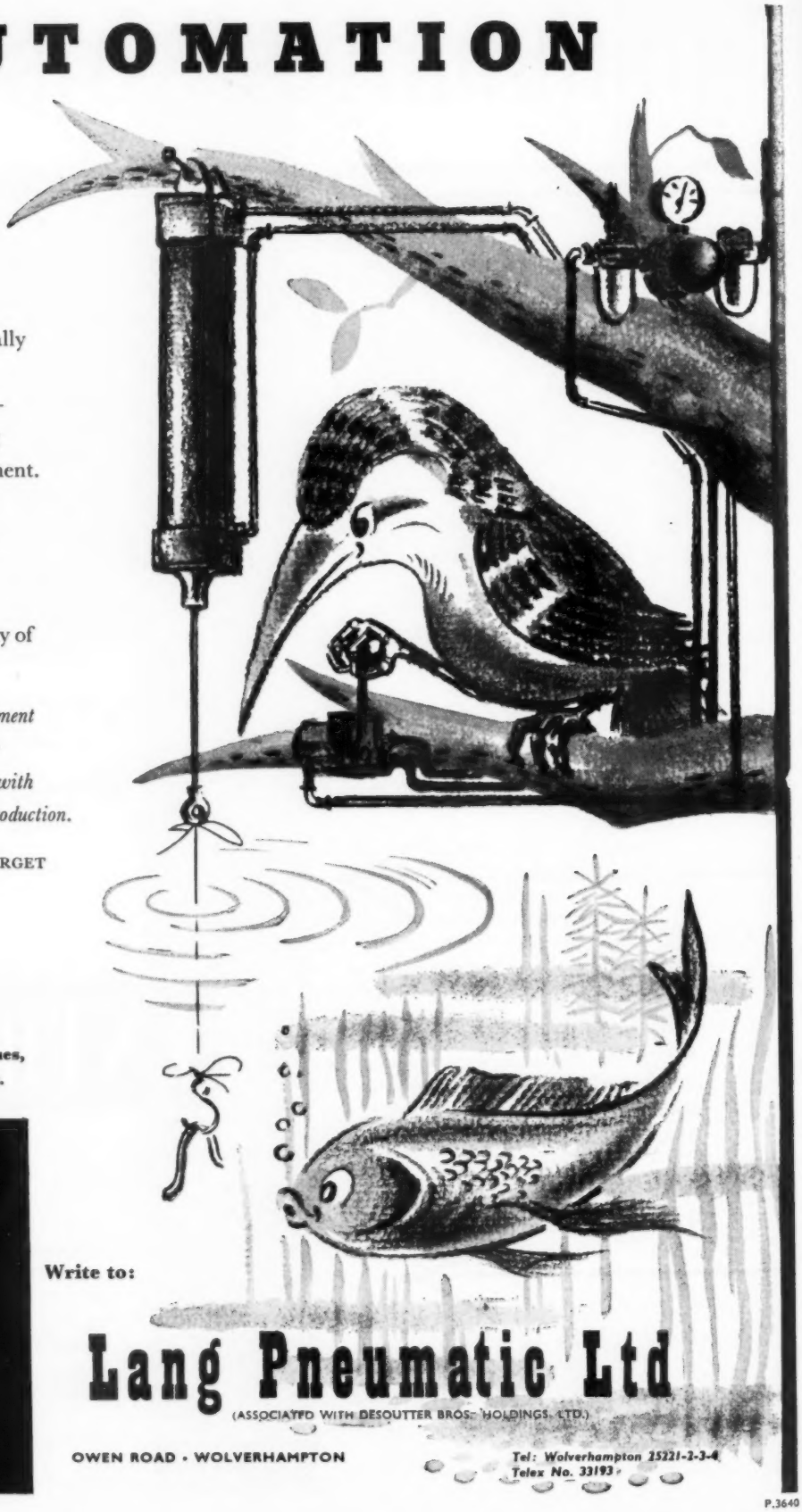

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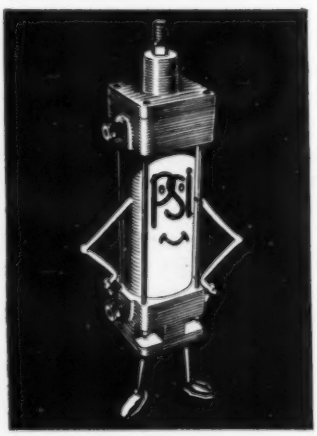

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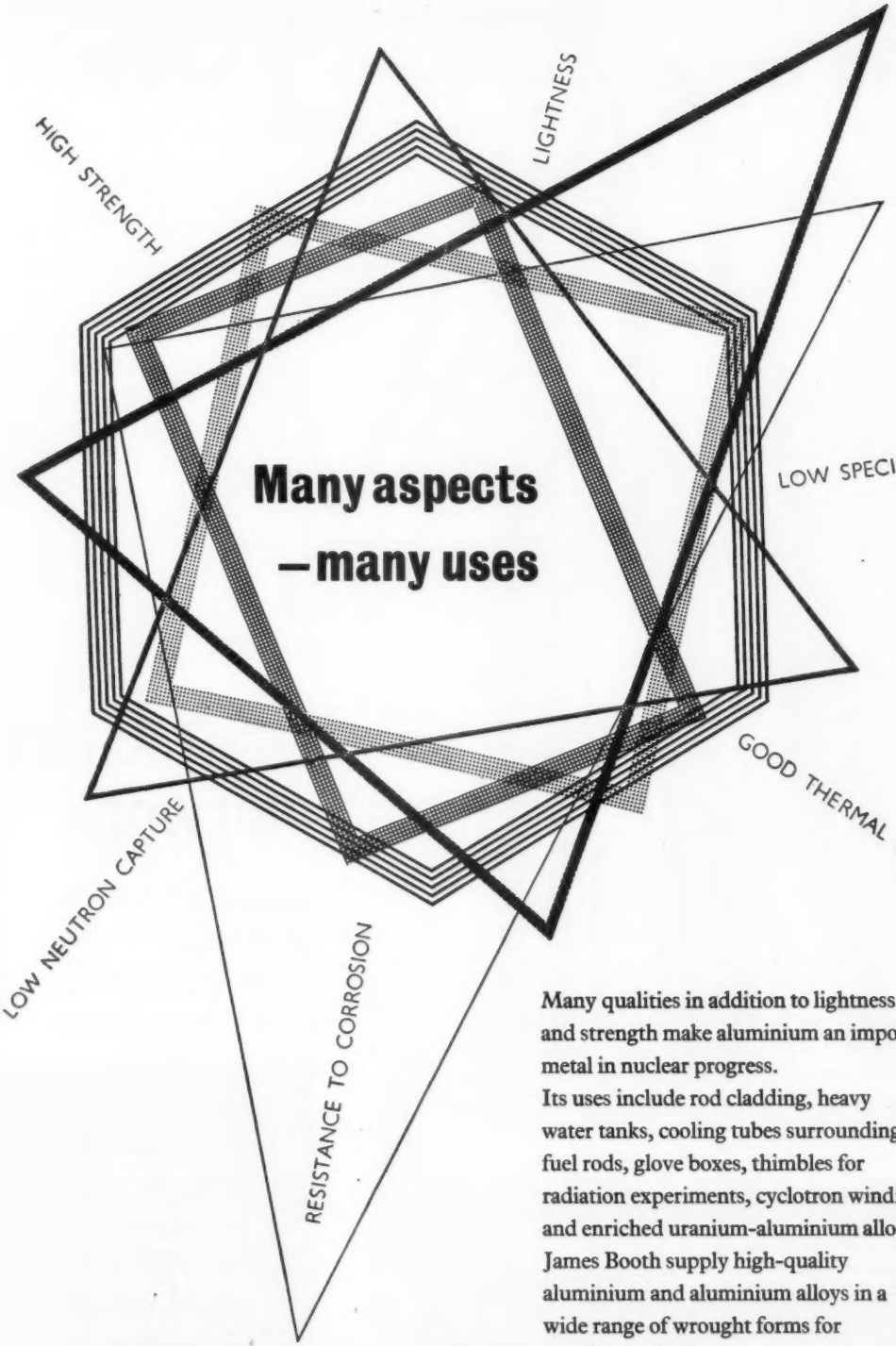

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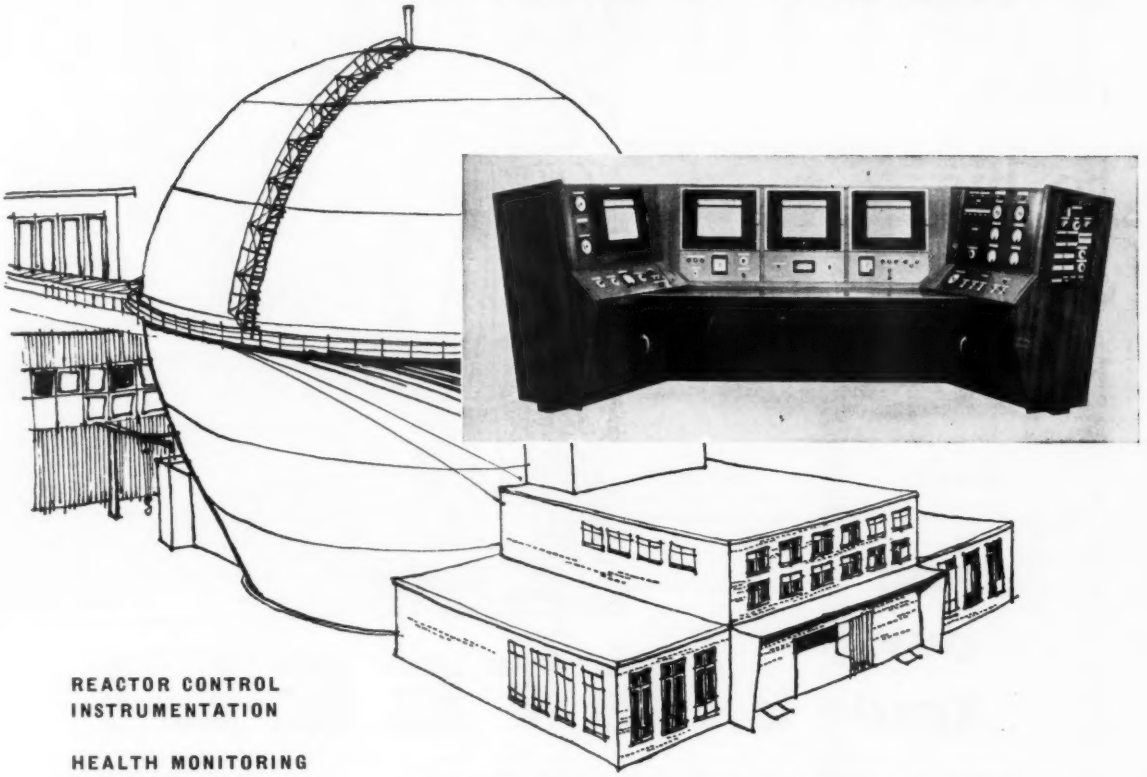

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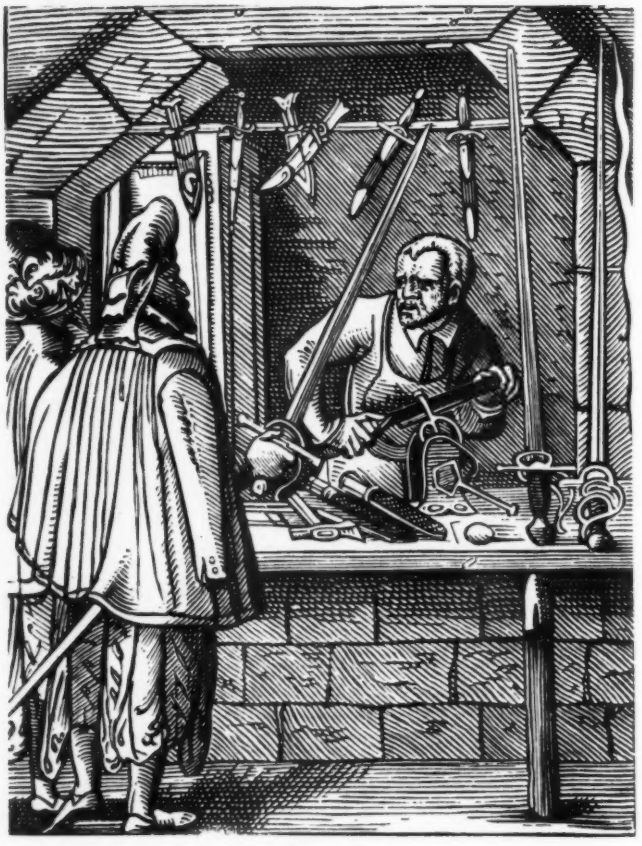

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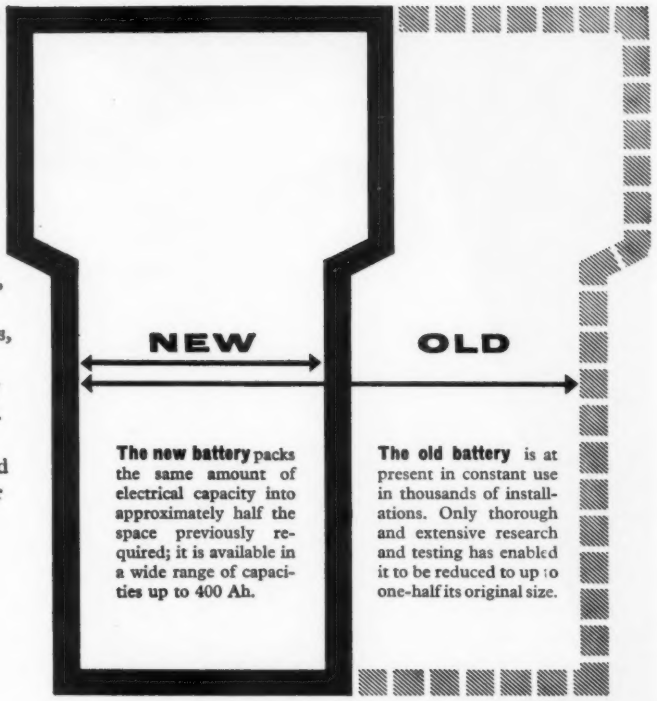
It is therefore the ideal cell for all stand-by applications, including emergency lighting in hospitals, cinemas, theatres and public buildings of all kinds, and auxiliary duties in both nuclear and conventional power stations.
The design of the cell results in a lower internal resistance and therefore provides a very much improved high rate performance, making it eminently suitable for switch-operating duties where high rates of discharge are involved.
With the great reduction of space required, and the renowned reliability and long life of its predecessors, this new Tudor high performance cell marks a great step forward in stationary battery design.



The new battery packs the same amount of electrical capacity into approximately half the space previously required; it is available in a wide range of capacities up to 400 Ah.

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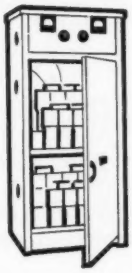

THE NEW SWITCH-TRIPPING EQUIPMENT

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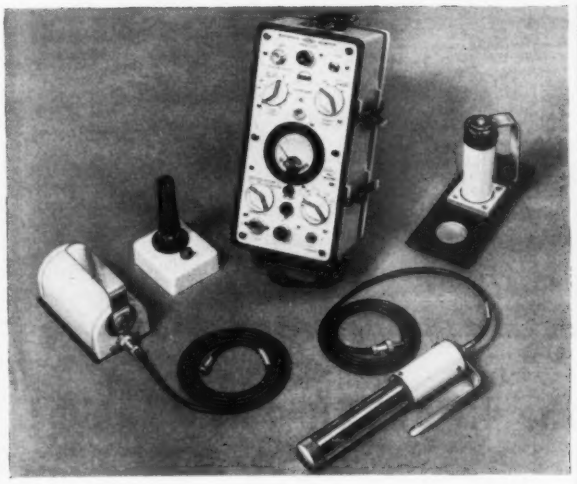

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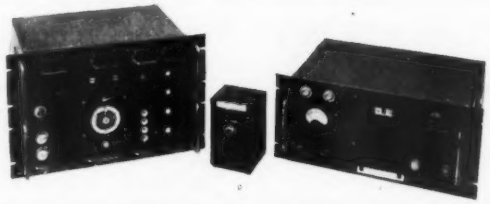

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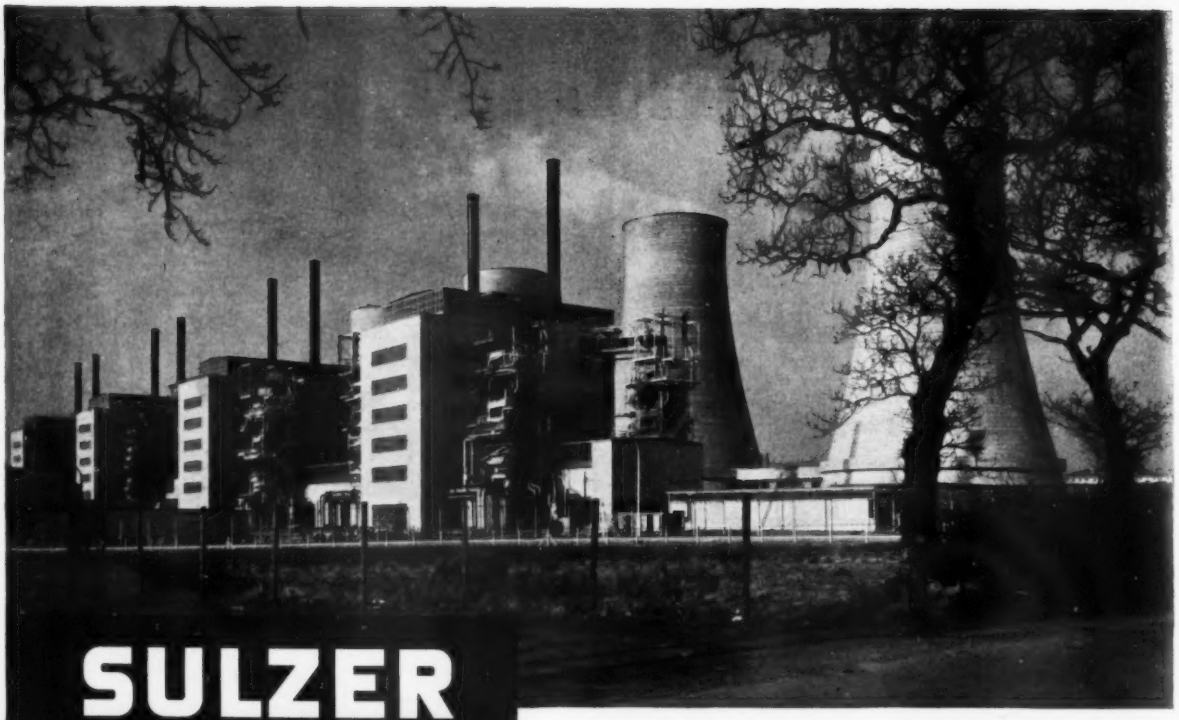

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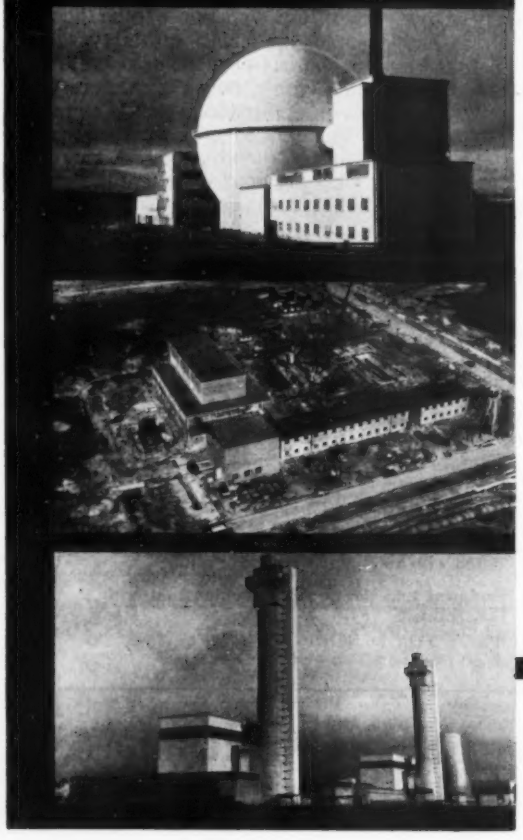

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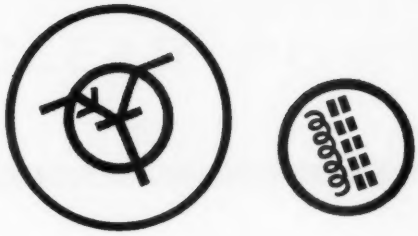

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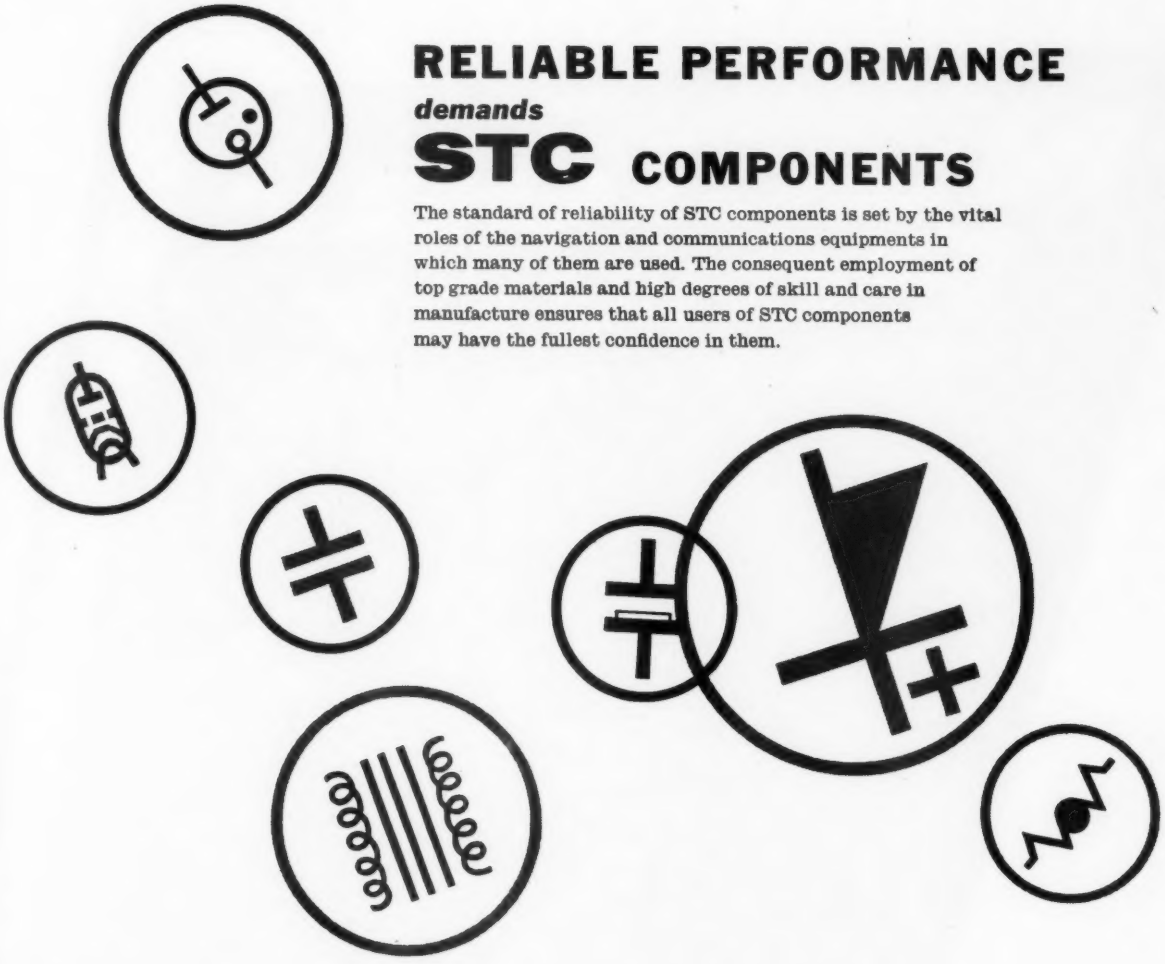

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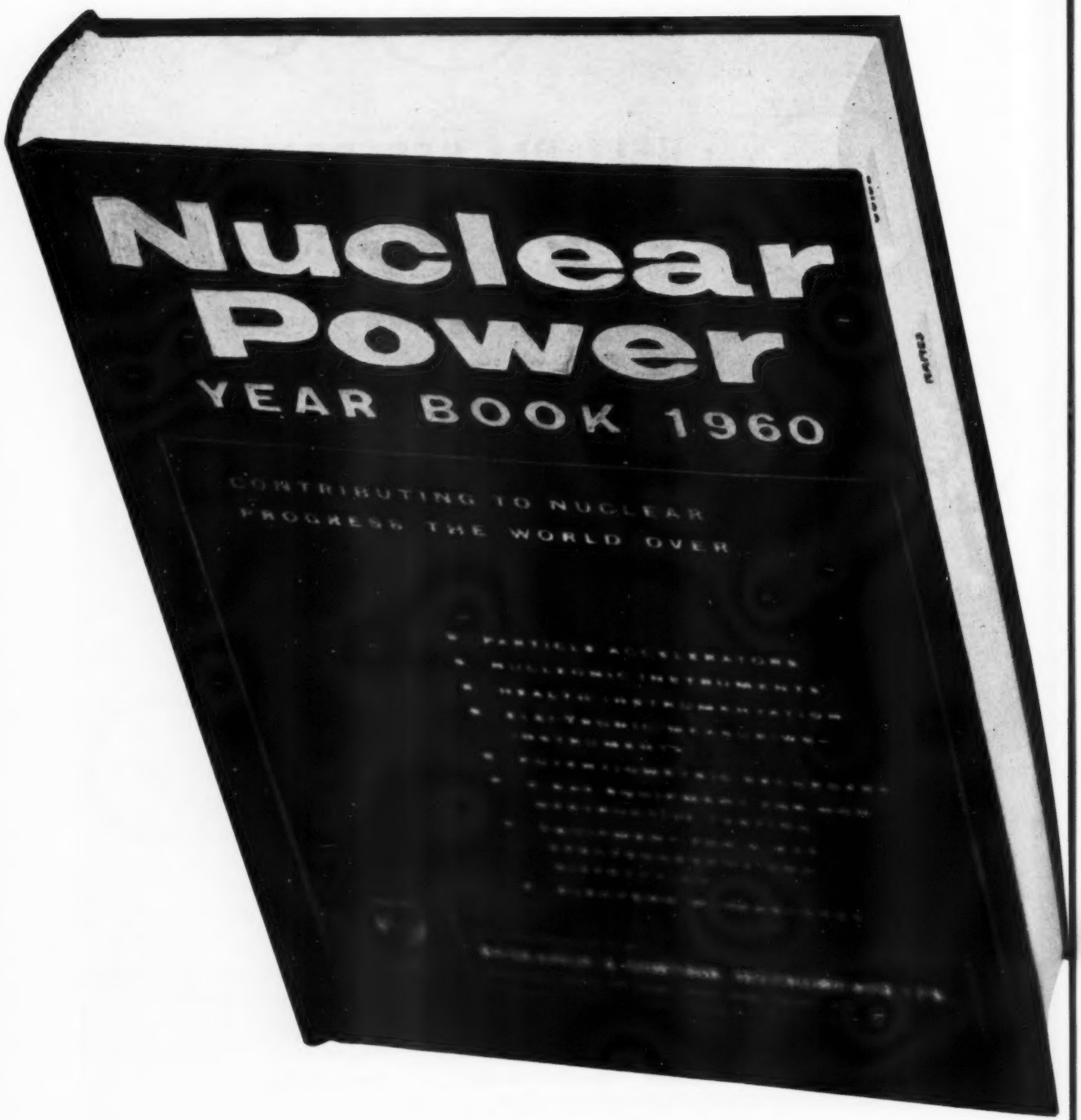
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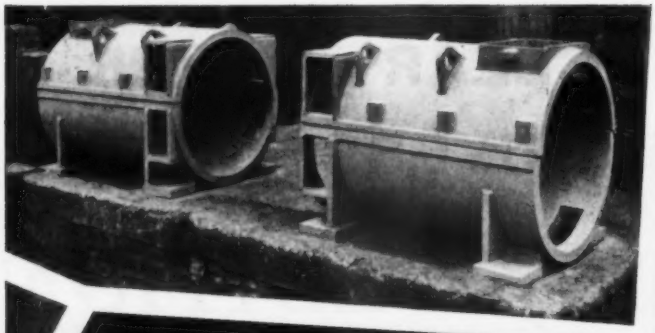

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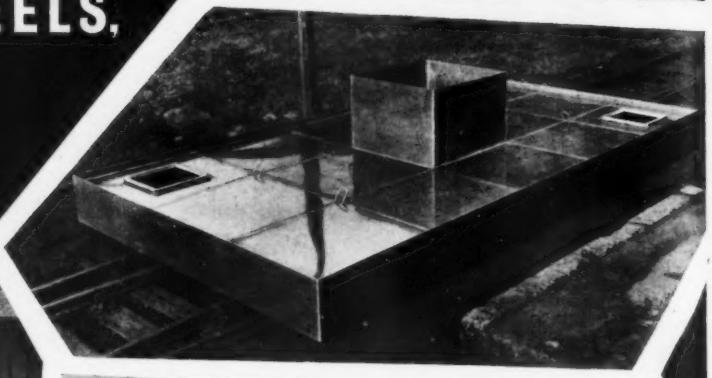

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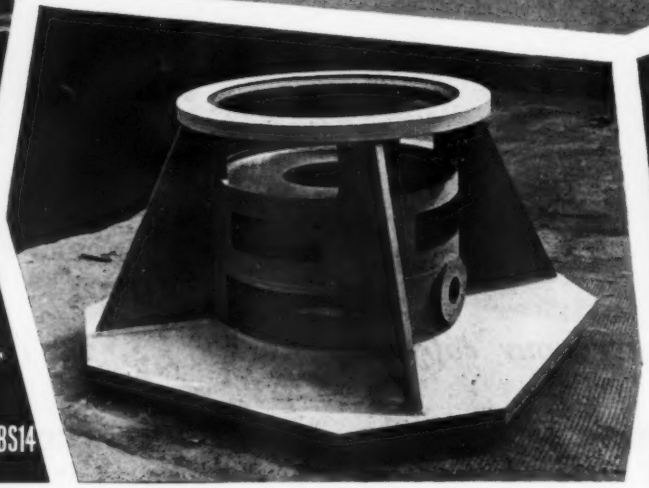

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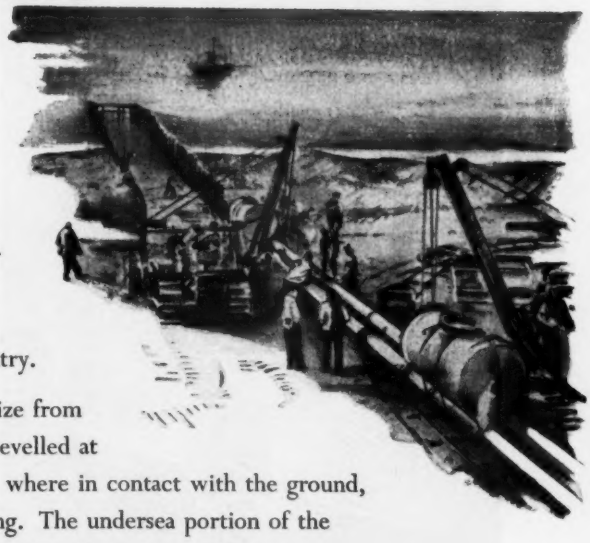

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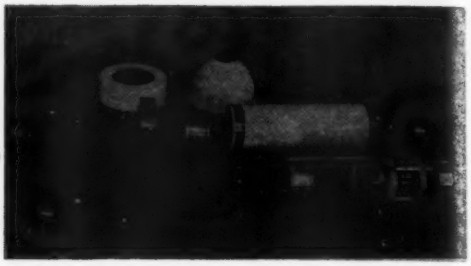

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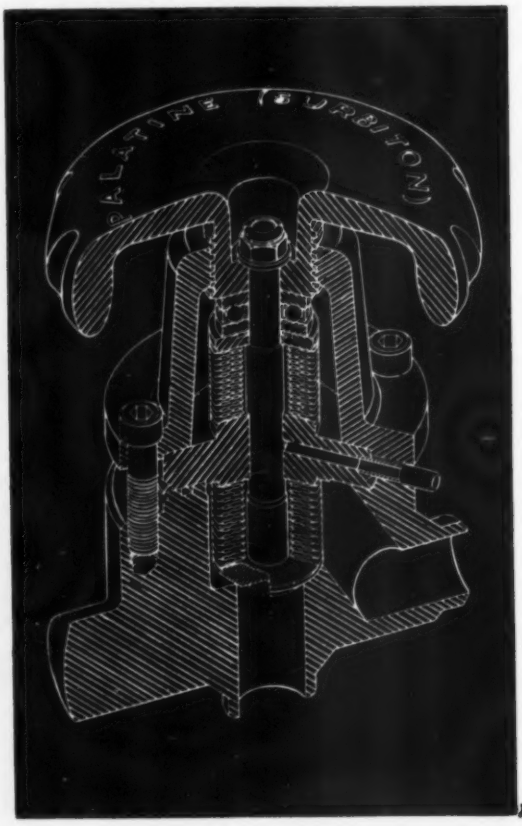

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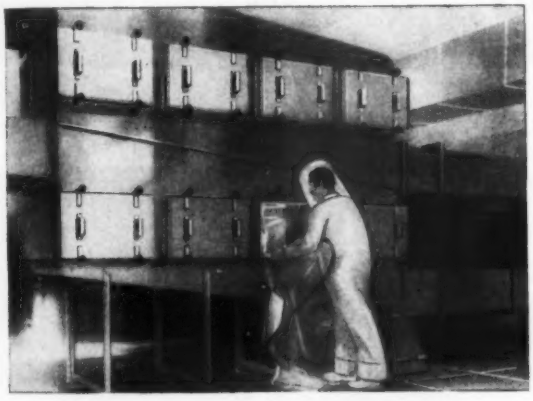

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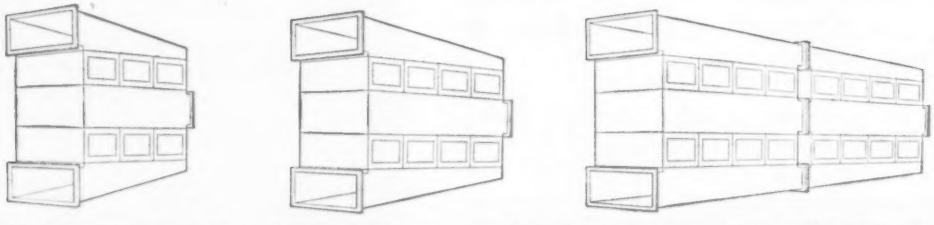

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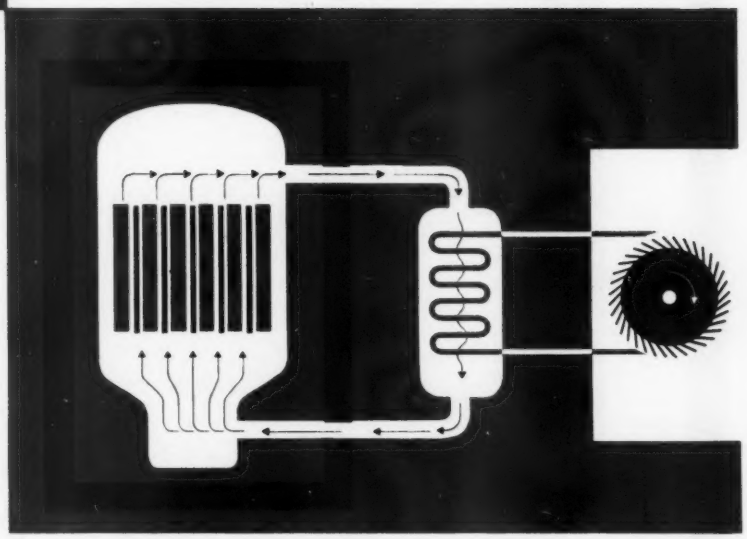

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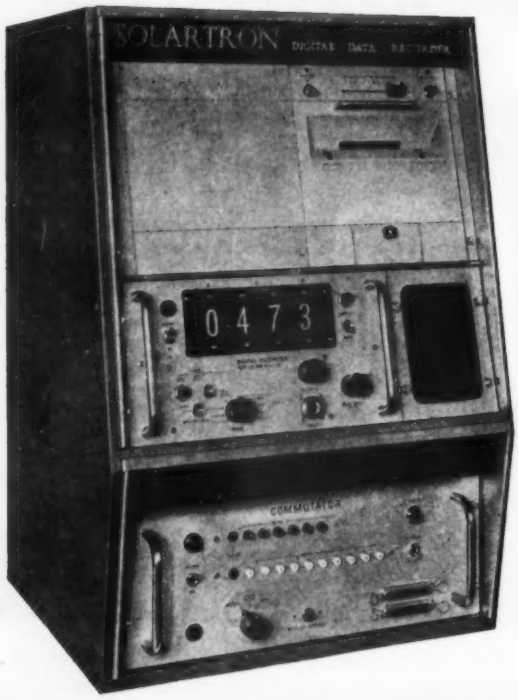

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Nuclear Power
REACTORS MATERIALS INSTRUMENTATION PROCESSES IRRADIATION
AUGUST 1960 VOLUME 5 NUMBER 52

VIEWPOINTS *letters to the Editor*

Reassurance on overseas tie-ups

SIR: Your correspondent, Mr. Wynsel, in your issue of last June, can be reassured. The British nuclear power consortia are alive to the fact that many overseas countries will wish to develop their own nuclear power projects and we are encouraging these developments. Some British groups have already concluded agreements with foreign companies and such collaboration is already evident in the Latina and Tokai-Mura projects. The sharing of British 'know-how' and experience with foreign firms establishes a common interest in the development of nuclear plant which will be of permanent value. Quite apart from these special agreements, it should be remembered that the industrial consortia have associated or subsidiary companies in countries throughout the world.

With regard to the appropriateness of 'turn-key' contracts it should be emphasised that 'turn-key' tenders are submitted in direct response to requests from potential customers. At present the majority of electricity undertakings want their nuclear power contracts to be organised in this way. Perhaps Mr. Wynsel is under the misapprehension that with a 'turn-key' contract the main contractor supplies all or most of the plant and civil works. In fact the main contractor carries overall responsibility but need not necessarily provide any 'hardware' himself.

K. J. WOOTTON
General Electric Company Limited, Erith, Kent

Teaching reactors

SIR: In reply to the letter of Mr. R. G. Scurlock (June issue), a distinction should be made between the training and research functions of a nuclear reactor at an educational institution. It is certainly true that many of the research areas of great current interest, such as massive radiation damage studies or neutron diffraction, require the use of high power reactors. However, the operating and capital costs of such reactors place them out of reach of most organizations other than national nuclear energy research establishments.

On the other hand, if we consider training functions, one is led to take exception to Mr. Scurlock's remarks. The situation is, in fact, rather the opposite of that which he describes. In the first instance, only low power reactors (say, below 100 kW) have sufficiently low fission product inventories to be safe in the ultimate sense of being unable to produce contamination of a large area. Only low power reactors have low enough costs (both operating and capital) to permit their being devoted to student use. Large reactors must be operated by professional crews on exacting schedules; such conditions are not conducive to learning or small scale experiments.

Only low power reactors have the accessibility and flexibility to permit students to change core geometry and materials (witness the Argonaut family of reactors, the free convection cooled swimming pools, and particularly the AGN-211, which was specifically designed to incorporate this flexibility). The difficulty of changing geometry or materials in high power reactors, coupled with the questions of cost, safety, and fission product inventory, militate against their use for this important type of training function. Again, one is much freer to experiment with reactor dynamics with a small reactor, for the same reasons, and because dynamic behaviour need not be limited by requirements of high capacity cooling systems.

As Mr. Scurlock notes, small reactors are useful in radiation chemistry and the production of isotopes. In particular, the great current interest in short lived isotopes can be satisfied only by close proximity to a reactor and, for most users, this necessitates a safe, low cost (and therefore low power) reactor. In addition, many other important areas of research are best accomplished on low power reactors, such as activation analysis, danger coefficient analysis, macroscopic cross-section measurements, exponential experiments, flux distribution measurements, low level irradiation studies, fission product release investigation, and, in fact, all but a small class of research functions.

The experience in the United States, where more than 30 low power research reactors are in service, has demonstrated their great usefulness. The fact that so many are in use, while no high power reactors are largely devoted to student use, nor easily available to students, is in itself indicative. Without these installations, our technical personnel would be almost entirely lacking in actual contact with reactors and in practical reactor-oriented skills.

H. MONTGOMERY
PROJECT MANAGER
GCRE-II
Aerojet-General Nucleonics, California

Radioisotope safety

SIR: In your second editorial (July) you rightly say that more information on the economic benefits possible from the use of radioisotopes should be fed to management and I think your idea of more regular compilation and publication of precise economic anlyses is good. But are the authorities really aware of the uncertainty which exists regarding safety? For example, the maximum permissible dose of radiation per 40 hour week is laid down by the British X-Ray & Radium Protection as 500 milliröntgens; but the International Committee on Radiological Protection gives 300 milliröntgens while another draft regulation lays down 100 as a safe maximum.

DAVID SERRY
Greenford, Middlesex

PUBLISHER'S COLUMN

From this issue, NUCLEAR POWER *will be printed on a new, lighter-weight paper. The paper used in the past has been criticized by readers on two counts: that it was too thick and resulted in a stiff, bulky journal which was difficult to handle, and, that it was too white and glossy and strained the eyes during reading. The new paper should keep the overall thickness of the journal within manageable proportions, even for the largest issues, and we hope that reading will be made easier by its off-white colour and less shiny appearance.*

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OPINION

Action on ships

BY JULY 29 the Ministry of Transport will have received the five designs for a nuclear powered tanker specified by the Yarrow-Admiralty Research Department. These are the outcome of the Galbraith Committee's evaluation last year, when seven industrial firms submitted studies covering pressurized water, gas and steam-cooled, boiling water and organic moderated reactors. Only the last two concepts were selected as having near-future potential, a decision that follows a recent one by the USAEC. That other systems are not to be ignored for the future, however, is indicated by the UKAEA in its annual report: the possibility of the steam cooled heavy water system, for instance, is being looked into.

The Government has been hard pressed for some time to declare its intention in this field and a firm decision in the very near future is wanted not only by the shipbuilding and reactor engineering industries, but also by the many people who look to Britain as a pioneer among maritime countries.

In its usual cautious manner, the Government, through Mr. Marples, recently stated that invitations for tenders did not commit it or anyone else to building a nuclear merchant ship. In the same breath, however, he considered that there existed an urgent need to go ahead with all possible speed and that sources of finance should be arranged to avoid further delay. Heavy costs have already been incurred by the various companies concerned, and this statement may have been made as a palliative. Rightly or wrongly, the attitude in this country is that where there is a line to be developed that may eventually lead to profit, then industry should pay its own way. However, both the two organizations which are primarily concerned with nuclear ship development, the British Shipbuilding Research Association and the Atomic Energy Authority, are either partly or wholly Government financed, and it should be carefully considered whether individual industrial participation in such an important project should be similarly treated.

The issue at stake now is not just one of prestige; even if we get a ship afloat in the relatively near future, we will only be in third place. What is more to the point is that the UK should adopt a realistic approach and exert every effort towards achieving economic competitiveness. That there is considerable development activity in Europe and elsewhere is clearly indicated in Mr. Burkett's survey appearing in this issue. Considering that over half the world's total tonnage in merchant shipping, and an even higher percentage of the world's tanker fleet, operates under European flags, vigorous participation by European maritime countries in the development of marine nuclear propulsion is a reasonable expectation.

At the moment there are three broad categories of development policy: the early construction of a PWR sea-going vessel with the minimum of research and development, in Germany, Italy, Denmark and the Netherlands; a more conservative approach with dependence upon a short-term programme of development work on the boiling water and the organic moderated systems in Britain, Germany, Sweden and Norway; and the long term approach, involving adequate investigations on more advanced types of reactor—the gas cooled system in particular—in France, Germany, Sweden and Denmark. It is to be hoped that the UK Government's advisers will have noticed that, in nearly every other country with declared plans for nuclear ship development, financial participation by the Government is an established fact.

The AEA reports

LITTLE THAT is shiningly new has come out of the sixth annual report of the Atomic Energy Authority; research has been following lines that are now familiar, and hopes for the economic future are still based on the fast breeder. The possibility of a power producing prototype in about seven years time, to be followed by a commercial design, is mentioned. In the advanced gas-cooled reactor programme, loss of ductility of beryllium under irradiation continues to be of concern, though reasonably encouraging preliminary results were obtained from the large irradiation programme conducted during the year.

Apparently the possibility of a 100 MWt experimental steam cooled heavy water reactor operating by the end of 1962, mentioned in the 1958–59 report, has gone; a newer concept—the steam generating heavy water reactor —is now in the forefront. There appears to be, however, little sense of urgency or excitement displayed. True, the AEA is thinking about collaborative research and development on the SGHW with the consortia; but it ploddingly says that a decision to proceed with building will not only depend on the results of further work which will be reviewed later this year, but also 'upon the availability of both technical manpower and financial resources.' It will be exasperating and shortsighted indeed if, after the project has been conceived, it is to be left still-born through lack of money and men. If the studies are successful, work should surely go aggressively ahead as soon as possible.

Much more heartening is the news that revenue from commercial operations during the year amounted to almost £M20, and that positive steps are being taken to proceed with the grant of licences to overseas organizations for the manufacture of natural uranium fuel elements by the Springfield process. Negotiations on this matter are going on at the moment with Germany and Belgium and, in an extension of this long-awaited display of minor enterprise, the AEA says it is prepared to consider requests from other countries wishing to make their own fuel elements.

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The Central Electricity Generating Board are just as concerned about this as they are about bringing in the power. For the nation has charged the Board with a double duty. Not only to maintain an efficient, economical electricity supply, but also to preserve the amenities of the country as they go.

That's why the new line will be planned so that it follows the dark background of a wood here; skirts a village there; crosses skylines in the most inconspicuous way to be found; and eventually reaches the town through its industrial suburbs.

These advertisements are appearing in the farming and country magazines. The Central Electricity Generating Board thank electrical contractors for their co-operation in the past, and know that they will do all they can to preserve the amenities of the countryside.

THE CENTRAL ELECTRICITY GENERATING BOARD CEGB

WORLDVIEW

the month in atomic energy

EUROPE

Consortia merger is on again

London Negotiations are still in progress on the setting up of a new company following the recent announcement that Atomic Power Constructions and the GEC-Simon Carves Atomic Energy Group have agreed to join forces to design and build nuclear power stations in this country. This latest combination reduces the number of consortia competing for nuclear power stations to three from the original five.

The bare announcement that 'as a result of further discussions,' APC and the GEC-Simon Carves group had agreed to join forces, followed earlier talks this year (see *Worldview*, April) which had ended in failure.

The original idea (see *Worldview*, November 1959) was to merge the two concerns more or less completely; but when it came to detailed arrangements, the two groups found their attitudes irreconcilable. Now it appears that these obstacles have been overcome and that there is general agreement on broad principles, and discussions that are taking place are merely on the organization of the new company. It is likely that the chief executives of this will be Mr. Arnold Lindley, managing director and vice-chairman of the GEC, and Col. G. W. Raby, managing director of APC.

The GEC-Simon Carves group is associated with Motherwell Bridge and Engineering and John Mowlem, while the Atomic Power Construction Group consists of Crompton Parkinson, Fairey Aviation, International Combustion and Richardsons Westgarth. It is also associated with Trollope and Colls, Holland & Hannen and Cubitts.

SEEN FROM ABOVE An aerial view of the 275 MW Berkeley nuclear power station after the completion of 3½ years construction work by the AEI-John Thompson Nuclear Energy Co. Ltd. In the foreground is the No 1 reactor. Top soil is being replaced and landscaping will begin soon

New fast research reactor for the UK

London A new zero energy fast breeder reactor to obtain information needed for the design of a prototype fast reactor is to be built at the UKAEA's establishment at Winfrith Heath, Dorset. Work to be carried out will complement that at Dounreay. The AEA considered the reactor earlier this year but had to await Treasury approval before proceeding (see *Worldview*, March, *Briefs*).

The reactor, called Zebra (Zero Energy Breeder Reactor Assembly) has been designed to permit the study of the neutron physics of a wide variety of fuel assemblies containing uranium and plutonium. The assemblies under study will be built up by loading fuel elements into a steel matrix (approximately a cube of side 10 ft). The fuel elements contain both fuel plates and plates of neutron-absorbing material: the latter will be used to simulate the nuclear properties of the coolant and structure material which would be required in a power reactor. Zebra will be operated at room temperature and the heat output from the nuclear reactions in the core will be kept very low so that no cooling system is necessary. It is planned to commission the zero energy reactor during 1962.

• **Euratom** Experimental and development work on a W. German OMR-type marine reactor project will be supported by Euratom, it was disclosed after the recent meeting between the Hamburg Gesellschaft fur Kernenergieverwertung (GKSS), the German Atomics Ministry and Euratom.

WORLDVIEW

Eurochemic plant gets under way

Mol, Belgium Work on the Eurochemic establishment here was officially inaugurated on July 7 by Prince Albert in the presence of representatives from the 13 participating countries. Construction of the first building—an administration block— has begun and the next steps will be a start on the laboratory for research on fuel element reprocessing methods (end 1960) and the reprocessing plant itself (1961), which will treat fuel elements from member countries. Present plans envisage test runs for the plant in 1963 with full operation during 1964. The cost of the laboratory and plant should account for about $M15 of the company's $M21·5 capital; the remainder will go on running expenses.

Outlining the scope of the plant, 'somewhere between a pilot and a production plant, with a capacity of 350 kg of irradiated fuel per day', Eurochemic officials said it had been decided to limit the acceptable degree of fuel enrichment to 5% and the irradiation to 10,000 MWd/tonne. Within these limits, the plant will be extremely versatile, capable of dealing with both uranium and oxide fuels, alloys such as uranium-molybdenum (up to 10% Mo) and, later, uranium-zirconium, and canning materials will include aluminium, magnesium, magnox, zirconium, zircaloy and stainless steel. Size limits for single elements or bundles have been set at 3·3 metres in length and 20 cms in diameter.

The work of Eurochemic has so far been carried out in laboratories put at its disposal by the Mol Centre. Here various sections of a typical reprocessing plant have been built and investigated.

The design of the main plant should be completed in a few months and the construction will be carried out, as far as possible, by companies within the member countries; several contracts are now being negotiated. The engineer-architects are the French Société Saint-Gobain, who hold 22 of the 430 shares, each with a nominal value of $50,000.

A number of private companies have bought shares from their country's holding (which is fixed by statute) and the present shareholders in Eurochemic are:

Shareholders	*Number of Shares*
The Government of the Federal Republic of Germany	50
Rheinisch-Westfälisches Elektrizitätswerk (RWE), Essen	1
Arbeitsgemeinschaft Deutscher Energieversorgungsunternehmen zur Vorbereitung der Errichtung eines Leistungs-Versuchs-Reaktor e.V. (AVR), Düsseldorf	1
Grosskraftwerk Mannheim AG., Mannheim-Neckarau	1
Steinkohlen-Elektrizität AG. (Steag), Essen	1
Badenwerk AG., Karlsruhe	1
Bayernwerk AG., Munich	1
Hamburgische Elektrizitätswerke AG., Hamburg	1
Preussische Elektrizitäts-AG., (Preussenelektra) Hanover	1
Kraftübertragungswerke Rheinfelden/Baden	1
Allgemeine Elektrizitäts-Gesellschaft (AEG), Frankfurt/Main	1
Interatom, Bensberg b.Köln	1
Degussa, Frankfurt/Main	1
Metall-Gesellschaft AG., Frankfurt/Main	1
Brown, Boveri and Co. AG Mannheim	1
Farbwerke Hoechst AG Frankfurt/Main	2
Farbenfabriken Bayer AG Leverkusen	2
The Government of the Republic of Austria	20
The Government of the Kingdom of Belgium	17
Société Belge de Chimie Nucléaire (BELCHIM)	27
The Government of the Kingdom of Denmark	22
The Commissariat à l'Energie Atomique, Paris	46
Société Saint-Gobain	22
Comitato Nazionale per le Ricerche Nucleari, Rome	37
Societe SORIN	5
Societe SENN	2
The Government of the Kingdom of Norway	20
The Government of the Kingdom of the Netherlands	29
Societe NERATOM	1
Junta de Energia Nuclear, Lisbon	6
Aktiebolaget Atomenergii, Stockholm	32
The Government of the Swiss Confederation	30
The Government of the Turkish Republic	16
Junta de Energia Nuclear, Madrid	30

Franco-US reactor agreement

Paris The Société Rateau has reached an agreement with Allis-Chalmers under which the US company grants the French firm an exclusive licence to manufacture, use and sell nuclear reactors and nuclear power stations. The territory covered comprises France, the Benelux countries, French overseas possessions and the countries of the French Community.

The licensing agreement will enable Société Rateau to share in the power construction programme within the framework of the Euratom-US agreement.

Other US-French agreements include that of Westinghouse-Schneider (Framatome) and Atomics International and Alsacienne de Constructions-Chantiers de l'Atlantique (Dynatom)—see *People*, this month. NUCLEAR POWER understands that the next agreement on these lines likely to be announced is that between Alsthom and the US General Electric. This may only be concerned with an exchange of technical information.

New UK Power Research Council

London The Minister of Power has reconstituted his Scientific Advisory Council and amended its terms of reference so that it covers all aspects of research and development concerned with fuel and power from the laboratory to industrial application. The council will also take over the functions of the Minister's Fuel Efficiency Advisory Committee and is invited to appoint a standing committee on fuel technology.

• **Italy** The RC-1 reactor supplied by General Atomics for the Casaccia nuclear study centre near Rome has started operating.

• **Denmark** Denmark and Britain have concluded an agreement aiming at a common research programme to produce nuclear power economically.

• **IAEA** Mr. Sterling Cole, the Director General of the IAEA, recently visited the UK at the invitation of the chairman of the AEA, Sir Roger Makins. He toured establishments and had talks with Sir Roger and Lord Hailsham.

• **Denmark** Danatom is to build a nuclear tanker and operate it alongside two conventionally-powered ships for comparison studies.

New European-US company is formed

Zurich A new European company, General Atomic Europe, whose primary aim will be the development of the high temperature gas-cooled central power systems in the 100 MW region, has been formed. It will be affiliated to General Atomic USA, a division of General Dynamics Corporation.

Present plans call for the location of offices and staff in Zurich starting in the autumn of this year. General Atomic Europe has also been incorporated in Düsseldorf and in Milan.

The objective of programmes of General Atomic Europe will be the achievement of the most advanced nuclear products, particularly those bringing about truly economic nuclear power in Europe. Primary emphasis will be placed on the high temperature gas-cooled reactor concept. The development of this system is a logical evolution of a 40 MW HTGR prototype which General Atomic USA is now building for 53 electric generating companies in the US. Dr. Peter Fortesque, former deputy chief scientist at Harwell, has been appointed chief research and development engineer (see *People*, page 114, this issue).

UK Nuclear Safety Committee

London Further emphasis on the question of nuclear safety problems was placed by the Government through its recent appointment of a 24-man committee to advise it on safety matters involved in nuclear science and engineering. The committee's terms of reference relate to safety problems under the Nuclear Installations (Licensing and Insurance) Act, 1959.

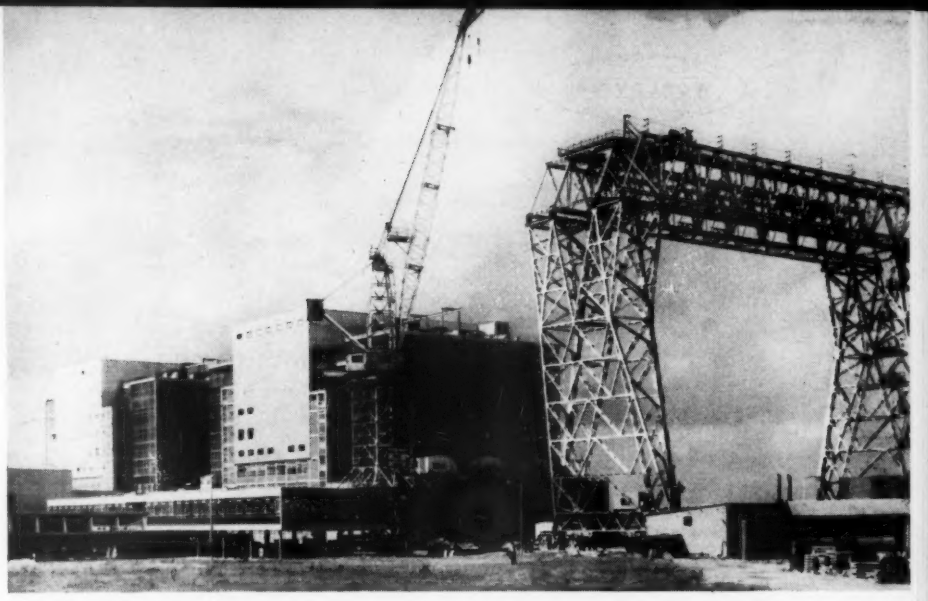
The chairman is to be Sir Alexander Fleck, former head of Imperial Chemical Industries.

CERN faces two major tasks

Geneva Two major tasks face the European Organization for Nuclear Research (CERN) during 1960, says the annual report for 1959. The first is the perfecting of the proton synchrotron itself and of arrangements for operating it; the other is the planning of the programme of research.

The report adds that towards the end of 1959, the synchro-cyclotron was closed down for three months in order to improve its shielding and to prepare for the introduction of stochastic acceleration.

During the year, the buildings originally planned were completed; the first of new buildings for the proton synchrotron, for generators for the propane chamber magnet and for the beam transport magnet were practically completed. The bulk of this work will be done during 1960 and should be finished in 1961.



PROGRESS AT BRADWELL Our picture shows a general view from the south of the No. 1 and 2 reactors at the 300 MW Bradwell power station. The stilted structure adjoining the end of the turbine house is part of the CEGB Operations Block. The contract for the station was awarded to the Nuclear Power Plant Company Ltd. in December 1956.

BEAMA looks at Common Market prospects

London An increase in the purchase rate of electrical products by the Common Market countries by 1963 of 44% over 1958 figures, from £M2300 to £M3300, is predicted in a 59 page survey of the Common Market by the British Electrical and Allied Manufacturers Association (Beama).

The report, Beama publication 173, is probably the first detailed survey of the potential market for its members' products in the Common Market ever prepared by a trade association in Britain. It points out that the Common Market presents a big challenge to British exporters, both in the size of its potential and the problems that will need to be dealt with in tackling it. 'It contains within itself powerfully established national electrical manufacturing industries', the survey adds. 'None as yet matches in total value of output the electrical manufacturing industry of the United Kingdom. But the advance of those of Western Germany and of France is rapid and is likely to be stimulated by the freer trading conditions within the Common Market, and based upon these, to expand into the further flung markets of the world. The total value of electrical manufacture within the 'Six' may be currently placed at some £M2400 per year; it is possible that it may rise by half as much again in the coming five years'.

In assessing the size of the future market for electrical products within the 'Six', the survey points out that sales of radio and communications equipment and domestic and commercial appliances are likely to rise faster than capital items; in the five years from 1959–63, the Common Market countries will have absorbed electrical products amounting to £M14,000—equivalent to 10 years' UK output at present production rates.

The survey points out that in 1958, the total installation of electrical goods as 'capital' goods by the 'Six' amounted to some £M1300. In the same year, total gross capital formation by the 'Six' amounted to about £M10,370. Of total capital formation, about one-eighth was represented by expenditure on electrical products. There are variations for individual countries but these are not unduly wide and the figures tend to confirm each other in showing the important part played by electrical products in current West European capital formation.

INSTALLATION OF ELECTRICAL CAPITAL PRODUCTS IN RELATION TO GROSS CAPITAL FORMATION 1958
(value in £ millions)

	Gross	Electrical	per cent
Belgo-Lux	629	60·3	9·6
France	3170	400·0	12·6
Italy	1930	280·0	14·5
Netherlands	700	67·4	9·7
W. Germany	3940	495·0	12·5
	10369	1302·7	12·5

On a.c. generators (on the whole in excess of 100 MW nominal rating), the anticipated installation rates in the public supply sector in France and Belgium for the years 1958–63 are considerably in excess of those achieved in the past years. In other countries of the 'Six', the future installation rates are below those recently achieved, notably in the Netherlands, where a high degree of generation concentration has already been achieved, and in Western Germany, where big capital investments of the reconstruction period have tended to furnish production capacity in anticipation of growth of demand.

Future installations of transformers are influenced by a complexity of factors, none of which dominates. Those installed in generating stations bear a measurable relationship to expansion in generating capacity and their quantity can be determined within reasonable margins, from actual data; some measure is also obtainable of capacity of future installations in users' premises and in the works of auto-producers from estimates of the development of high-tension supplies and auto-producer operation. Estimates of installations in supply networks, need, however, to be based almost solely upon assumption of expansion of existing installations calculated on past trends.

'The Beama Survey of the European Common Market for Electrical Products' published by the British Electrical and Allied Manufacturers' Association (Inc), 36 Kingsway, London WC2.

Yugoslav isotope output

Belgrade Production of isotopes in Yugoslavia, which started recently, will be increased gradually until all domestic requirements will be covered. Production is centred at the Vinca research centre where a Soviet-built 6·5 MW heavy water reactor was completed at the end of last year.

WORLDVIEW

OVERSEAS

Sharp sales rise in US nuclear industry

New York The US nuclear industry has now a valuable guide to future market potentials in the shape of a special report entitled 'Business Statistics on the Atomic Industry 1954–58.' This report by the Atomic Industrial Forum details not only the extent of product shipments during the period covered but also to the types of market to which the equipment, services and materials were delivered.

A major portion of the data contained in the report relates to the sale of nuclear reactors, components, materials and services to and by the atomic industry. Because of the research and development character of many of the activities in the industry, sales data has been supplemented with information on research and development expenditures, capital investment, and employment of scientific and technical personnel.

Among the main points of the report is that American industry is estimated to have sold and delivered approximately $M1500 worth of nuclear reactors, components, materials and services to the US Government and US industry and to foreign markets during the five year period 1954–58. This estimate is projected from the $M933 worth of sales reported by 196 of the companies and institutions who took part in the survey.

These totals do not include equipment and services for the nuclear weapons programme or nuclear propulsion reactors for the naval and aircraft programmes. Also excluded are most of the costs associated with operating Government-owned development and production facilities.

More than 75% of the market for the $M933 reported sales was accounted for by US Government contract and subcontract purchases. Approximately 20% of the total was for products and services delivered to US industry and less than 4% went to foreign markets.

One of the more interesting facts gleaned from the survey is the striking upward trend of sales. In the five year period from 1954 to 1958, there was, with a single exception, a steady increase in the annual dollar volume of shipments. The largest percentage increase took place between 1955 and 1956 and the smallest between 1957 and 1958, but the average yearly increase in dollar volume of shipments during the five year period was 88%.

Another fact is that between 75 and 100 companies are known to be engaged in the manufacture and sale of radiation instruments and/or instrument components. Many of these companies are quite small—i.e. their total annual sales may run well below $M1. Many of them manufacture only a single type of instrument while others manufacture only components.

In research and development, over $M224, about $M124 privately and $M100 in government funds, were spent in the 1954–58 period. Of this total, approximately 45% was reported for design and development of reactors.

Capital investment during the same five year period amounted to approximately $M465 in private funds. The largest single category of private capital investment, accounting for 31% of the reported total, was made on facilities for the milling and processing of uranium ores.

Figures for the latest year in the survey, 1958, show that over $M650 worth of nuclear products and services are estimated to have been delivered by American industry. Here again, neither the reported nor the estimated sales totals include equipment and services for the nuclear weapons programme or nuclear propulsion reactors for the naval and aircraft programmes. More than 65% of the $M404 total reported by 196 of the companies taking part in the survey, is attributable to the shipment of components, equipment and materials for nuclear reactor systems. An additional 17% was accounted for by the sale of services, a major portion of which were performed in connexion with the development of nuclear reactors.

'Business statistics on the atomic industry 1954-1958'. Atomic Industrial Forum, 3 East 54 Street, New York 22, New York. 36 pages. $3·50.

• **Israel** Israel's first research reactor at Nahal Sorek, south of Tel Aviv, is now in operation and is expected to reach its 1 MW power level within the next two months.

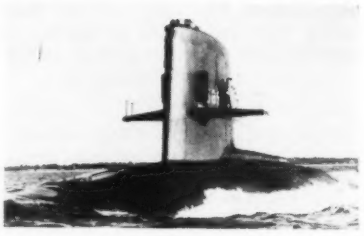
• **Philippines** The first components for the one MW open pool research reactor for the Philippine Atomic Energy Commision have been completed by the US General Electric.

• **UNO** A third United Nations International Conference on the Peaceful Uses of Atomic Energy, to take place in Geneva in 1962, or possibly 1963, has been recommended to the General Assembly by the Secretary-General, Dag Hammarskjold.

• **Canada** Atomic Energy of Canada has shipped more than a million curies of Canadian-produced isotopes since the first shipment 12 years ago.

• **Argentina** The Mercantile Metal and Ore Corporation of New York presented the highest bid and won 200 tons of beryllium ore at the first Government auction held in Buenos Aires.

• **Lebanon** Large uranium ore deposits are reported in the Barouk and Dahr el Baydar mountains of Lebanon.



NEW US SUBMARINE The US Navy's newest nuclear powered submarine, 'Scorpion', on her maiden voyage. She was built by the Electric Boat Division of General Dynamics and is a sister ship of the 'Skipjack', said by the Navy to be the fastest submarine afloat

US supplies first South African research reactor

Pretoria The first South African research reactor is to be built by the Allis-Chalmers Manufacturing Company. The work will be done under the terms of an agreement signed recently in the US between the South African Atomic Energy Board, the Roberts Construction Co. of South Africa and Allis-Chalmers Nuclear Power Department.

The reactor, an advanced version of the ORR tank type now operating at Oak Ridge—will operate at first at 6·6 MW but will be designed for ultimate operation at power levels as high as 20 MW. It is similar to the Swedish R-2 reactor now in operation at Studsvik (see *Worldview*, July).

Trombay reactor goes critical

Bombay The Indian research reactor at Trombay, the largest in Asia, has gone critical, four years after work on its foundations began. The reactor was a joint Canadian-Indian effort and is based on the Canadian NRX reactor at Chalk River. It is expected to operate at its full output of 40 MW on a routine basis in the autumn. Called the CIR, the reactor is fuelled with natural uranium and moderated with heavy water.

Michigan boiling water reactor agreement reached

Washington Under an agreement reached between the USAEC and the Consumers Power Company, Michigan, the company is to be responsible for the design, operation and construction of a 50 MW high power density boiling water reactor power plant. The plant is scheduled to go critical in September 1962 and it is hoped that with further research and development, the plant's capacity will produce a maximum of 75 MW.

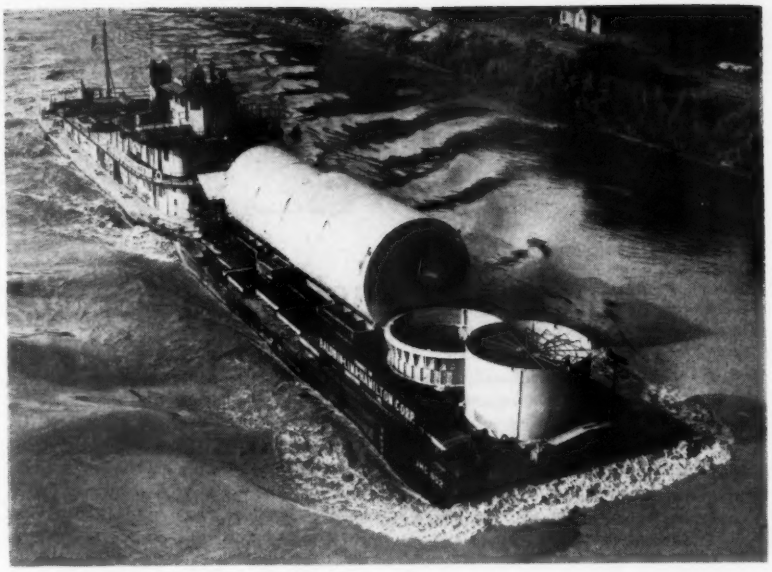
The agreement also provides for the General Electric Company of San Jose, California, and Consumers to receive financial help from the Commission in pre- and post-construction research and development. Fuel use charges during the first five years of operation are to be waived. Capital costs, including site and site preparation, are estimated at nearly £10,000,000.

Consumers are to make the plant available four and a half years after criticality, for research and development into increasing the power density of uranium oxide fuelled boiling water reactors.

• **Indonesia** Indonesia and the USSR have signed an agreement on co-operation in the peaceful uses of atomic energy under which the Soviet Union will aid Indonesia in the building of a research reactor.

• **India** The Indian Atomic Energy Commission is to start mining uranium ore in Bihar State.

ENRICO FERMI WORK GOES ON This latest picture of progress on the Power Reactor Development Company's Enrico Fermi project shows a heat exchanger being lowered into its shell in the reactor building. The USAEC and the PRDC have appealed against a court decision which would have meant a stoppage of work on the plant (see 'Worldview', July, p. 66)



GENTLY DOES IT The 80 ton reactor vessel, 65 ton containment tank, 13 ton upper cavity linear ring and 4½ ton upper thermal shock liner ring for the 75 MW Hallam, Nebraska, power plant, approach the last leg of their journey up the Missouri River. The Hallam plant will have a sodium cooled, graphite moderated reactor and is scheduled for operation by Consumers Public Power District of Nebraska in 1962

New use for uranium forecast

Winnepeg A new use for uranium in steel production has been developed by the Canadian Government, according to Dr. John Convey, Federal Director of Mines and Surveys.

Dr. Convey told the recent convention of the Engineering Institute of Canada that considerable amounts of uranium were already being used in the production of steel. If the new process were adopted for the manufacture of low alloy steel, an outlet for much of Canada's uranium output would be found.

The Department of Mines and Surveys, which developed the process in co-operation with uranium producers, had already received inquiries from the US, the UK and many European producers.

In essence, the process calls for the addition of one to four pounds of uranium to a 500-pound steel melt which helps the steel to resist corrosion, improves the fatigue life of the metal and has other beneficial results. Since low alloy steel production in Canada totals many thousands of tons annually, a new market seems to be assured for the country's faltering uranium industry.

• **United States** The Lockheed Aircraft Corporation's Georgia Division is to build a training reactor to be exhibited in South America by the USAEC.

• **Canada** Estimates of the cost of the 200 MW Douglas Point nuclear power station have been raised from $60 million to $81·5 million.

Dresden reaches full power

New York The Dresden, Illinois, nuclear power station reached full power on June 30. The station has a 180 MW boiling water reactor designed and built by US General Electric for Commonwealth Edison Co. and the Nuclear Power Group Inc.

The reactor went critical on October 15, 1959, some six months ahead of schedule. It is to be turned over to Commonwealth Edison later this year (see *Worldview*, July, p. 65).

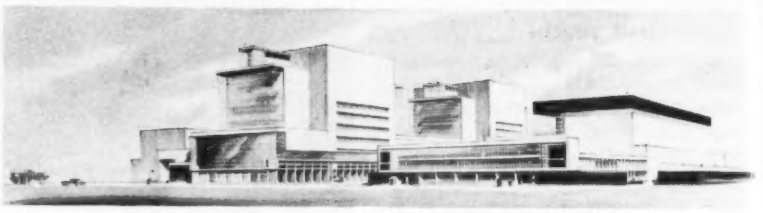
• **Africa** Exploitation of uranium ore deposits in French Equatorial Africa is likely to start in 1961. The deposit, estimated at 20 million tons, is owned by Mines d'Uranium de Franceville.

• **Japan** A trade school to teach nuclear engineering will open in eastern Japan before next April. It will be sponsored by the Japan Atomic Industrial Forum.

ROBENS

In our *Worldview* story, page 64, July, headed 'Robens to be NCB Chairman', it was incorrectly stated that Mr. Robens was adviser on labour relations to the Nuclear Power Plant Co. Mr. Robens is, of course, adviser on labour relations to Atomic Power Constructions Ltd.

This impression of the UK's sixth commercial station shows one reactor on the left, the second in the centre behind the administration block and the turbine hall on the right



Dungeness nuclear power station

TWELVE MONTHS after consent for the construction of the Dungeness nuclear power station in Kent was given by the Minister of Power, has come the announcement by the Central Electricity Generating Board that it intends to place a contract for the building of this station with The Nuclear Power Group. Work will begin this month, with the handing over of Britain's sixth commercial nuclear power station scheduled for 1965.

No radical changes in design for this 550 MW magnox station were expected and none are apparently contemplated. The Nuclear Power Group, in its first contract since it was formed in January this year, will build a station containing two carbon dioxide, gas-cooled, graphite-moderated, natural uranium fuel reactors operating on the same principle as those for stations already being built for the CEGB. The principal structures will be two reactor buildings, a turbine house and an indoor switching station.

The reactors

The two identical reactor units, of approximately 840 MW thermal output each, will have an inner core and an outer 'shell'. The prism-shaped graphite core is made up of large octagonal and small square bricks and is supported on a grid; its equivalent diameter will be 49 ft 10 in. and it will be 27 ft 10 in. high. The 'shell' containing this core is a spherical steel pressure vessel 62 ft 6 in. mean dia., 4 to 4½ in. thick and having a total weight, including core support grid, of 1960 tons.

The vessel is surrounded by a primary biological shield of concrete through which pass the gas ducts, 6 ft 6 in. dia., to four boilers. Dry carbon dioxide at a pressure of 283 lb/in²a is circulated between the reactor core and the boilers by four blowers driven by back pressure steam turbines.

Turbine house

The turbine house will contain four 142·5 MW turbo-alternators with the steam and electrical connections between reactor units and turbine house being taken underground through tunnels. Four boiler shells, which will be site fabricated, will weigh over 300 tons each and will be 72 ft high with an internal diameter of 23 ft 6 in. The thickness of the plates will run to 3⅞ in. Steam will be generated in the boilers at two pressures, 1418 lb/in²a and 590 lb/in²a. All the higher pressure steam will be passed through the back pressure turbines driving the blowers. These turbines exhaust at the LP pressure, and, after reheating in the boilers, this steam is passed with the LP steam to supply the main turbines. The overall station efficiency when working at these conditions will be 32·9%.

Present orders

For TNPG, the Dungeness award will bring orders on hand to more than 1000 MW for nuclear generating plant. Before the formation of the group, the contract for Berkeley Nuclear Power Station (275 MW) was awarded to AEI-John Thompson Nuclear Energy Company and Bradwell (300 MW) was awarded to the Nuclear Power Plant Company Ltd. Both awards were made in December 1956. In addition, the station at Latina, south of Rome, is being built by NPPC and AGIP Nucleare.

The Dungeness station itself is to be sited in what is now termed a 'conservative' position—away from the main population centres. The nearest town, Lydd, is four miles away and has a population of just over 3000; Dover is 28 miles away and London 74 miles distance. The working area of 112 acres (when completed the station will occupy 40 acres) will be on a shingle, triangular-shaped headland projecting nearly five miles into the sea.

DUNGENESS TECHNICAL DATA

PERFORMANCE :	
Net electrical output	550 MW
Heat output per reactor	835 MW
Efficiency	32·9%
Reactor gas bulk outlet temperature	410°C
Reactor gas inlet temperature	250°C
Nominal max can surface temperature	442°C
Nominal max uranium temperature	563°C
HP steam pressure at blower TSV	1410 lb/in²a
HP steam temperature at blower TSV	392°C
LP steam pressure at main TSV	550 lb/in²a
LP steam temperature at main TSV	391°C
Feedwater temperature	180°C
FUEL :	
Number of fuel channels per reactor	3876
Number of elements per channel	7
Overall length of fuel element	41·7 in.
Dimensions of uranium rod	37·6 in. × 1·10 in. dia.
Total weight of uranium per reactor	298 tonnes
CORE DIMENSIONS :	
Diameter of active core	45 ft 4½ in.
Height of active core	24 ft
Diameter of reflector	50 ft
Height of reflector	27 ft 10 in.
Lattice (square) pitch	7·75 in.
GAS CIRCUIT :	
Mean diameter of reactor vessel	62 ft 6 in.
Reactor vessel general thickness	4 in.
Gas working pressure	283 lb/in²a
Number of gas circuits per reactor	4
Diameter of gas ducts	6 ft 6 in.
Power input per blower	7 MW
Overall height of boilers	75 ft
Internal diameter of boilers	23 ft 6 in.
Shell thickness (graded)	3½ in. to 2⅞ in.
TURBO-ALTERNATORS :	
Number of main turbo-alternators	4
Continuous maximum rating/set	142·5 MW
Speed	1500 rev/min
Generator voltage	13·8 kV
Vacuum	28·9 in. Hg
Exhaust wetness	14·3%
Total circulating water quantity	353,000 gal/min
LAYOUT :	
Distance between reactor building centres	426 ft
Length of reactor building	316 ft
Length of turbine house, only	385 ft

Sixth annual report of the UKAEA

A YEAR OF 'steady progress' in which revenue from commercial operations came to nearly £M20 and where there was a consolidation of effort, are the main impressions gained from the Sixth Annual Report, 1959–60, of the UKAEA, published on July 13. Staff increased from 35,260 to 38,500; the estimated net expenditure for 1960–61 is £93,293,000 against £92,433,010 a year earlier and hopes for low cost nuclear power still hinge on the fast breeder reactor system.

Reactors

Experiments both in materials testing reactors and at Calder Hall have shown that the rate at which Wigner energy builds up decreases more rapidly than had been expected as irradiation proceeds. On the strength of this, the Authority decided to withdraw their recommendation that fuel channels be sleeved so as to raise the bulk graphite temperature. Work has also shown that reaction between graphite and carbon dioxide under the influence of irradiation was not likely to present problems in magnox reactors. But a large programme on it has been undertaken in connexion with the Advanced Gas-cooled Reactor project.

Recent studies have confirmed that this system offers the best prospects for the early achievement of competitive nuclear power in the UK. A considerable amount of work has been devoted to the control of large AGR systems.

The report reaffirms faith in the fast breeder system, and a start was made during the past year on the study of some suitable fast reactor systems for civil power production and the optimization of the characteristics of such systems. These studies will pave the way for the investigation of the design of a prototype on which effort will be increasingly devoted in the coming year. At Dounreay, some trouble was experienced through the formation of oxides in the coolant and improvements were made to the oxide clean-up circuits. At the conclusion of the initial low-power stage, the reactor was shut down for modifications to the core, involving the fitting of an adaptor to part of the core so that other, more advanced, types of reactor fuel elements could be tested.

During the last year, in the course of the design study of a steam-cooled heavy water (SCHW) reactor prototype, a further development of this concept has taken place; instead of generating the steam in external heat exchangers, it is now proposed that the water should be evaporated in the reactor core itself. This idea of a steam generating heavy water reactor (SGHW) offers savings on capital cost since the light water coolant in the core would contribute towards moderation and the investment of heavy water would be reduced; furthermore, there would be no need for external heat exchangers.

The immediate object of a study is 'a reactor using water and steam coolant in pressure tubes inserted through a heavy water container, steam being separated outside the reactor before being returned for superheat.' The combination of the two different moderators and the use of the boiling principle introduces novel problems in reactor physics and stability, and the performance cannot at present be predicted to the required accuracy. Preliminary physics experiments will be carried out in DIMPLE to assist in assessing the feasibility and performance of the system. Work has also proceeded on experimental investigations of heat transfer problems in water/steam systems and on a feasibility study of a possible prototype power reactor.

A decision on whether to proceed with the construction of an SGHW will depend upon the results of this further work, which will be reviewed later this year, and on the availability of technical manpower and financial resources.

Design studies of possible marine reactor systems continued; the conclusion is that reactor systems on known techniques will not be competitive. Studies are continuing on organic liquid-cooling and boiling water systems and the possibilities of steam generating and steam-cooled heavy water systems for ships.

An extension of collaboration with the consortia in connexion with other reactor systems, in particular with the steam generating, heavy water-moderated reactor, is under consideration.

For the high temperature gas-cooled reactor (HTGC), it might be possible to start the system with plutonium rather than with uranium-235, the report states. Graphite of the required degree of impermeability for canning has now been made, but its performance under prolonged irradiation has yet to be established.

Fuels

Development of large-scale manufacturing processes for slightly enriched uranium oxide pellets has been undertaken and already several tonnes of such pellets have been successfully made to design specification. Negotiations are proceeding with Germany and Belgium regarding the possible grant of licences by the Authority for the manufacture overseas of natural uranium fuel elements by the Springfield's process.

Loss of ductility of beryllium under irradiation continued to be of concern, but preliminary results obtained during the year from the large irradiation programme, were 'reasonably encouraging.' Parallel with the development of beryllium as a canning material, was the investigation of the use of stainless steel. The development of greatly improved heat transfer surface now enables the total amount of stainless steel to be kept small and mitigates the high neutron absorption and low thermal conductivity of stainless steel.

Uranium stocks will be larger than necessary for some years. It is now improbable that uranium producers outside the US will make any substantial new sales of uranium for the next decade. Demand is unlikely to build up again until sometime in the 1970's.

Radioisotopes

Sales of radioisotopes increased by 25% over the previous years, to £M1·1. Over half the sales (60%) were for export, while medical users took half the total of 35,000 deliveries during the year. Two new laboratories were brought into commission at Amersham at the end of the year. One is for the synthesis of organic compounds labelled with carbon-14 or with tritium, the demand for which compounds has increased ten-fold in the past ten years. The other is for the manipulation of radium and related elements.

CTR work

The design of the ICSE (Intermediate Current Stability Experiment), is now well advanced and orders have been placed for some of the main components. This apparatus will be erected at the Culham Laboratory which will be the Authority's thermonuclear and plasma physics research centre. The first building to be built will be for ICSE.

Preliminary design studies confirm that this system combines many of the advantages of boiling and steam cooling

The spray cooled reactor

by J. G. COLLIER, B.Sc.(Eng.)
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SPRAY EVAPORATION is a method of reactor cooling in which a mixture of steam and water is injected into the fuel channels, rather than single-phase water or steam. A spray-cooled reactor thus lies between a boiling reactor and a steam-cooled reactor and possesses many of the advantages of both. The method was originally proposed (*1*) as an application of the climbing film principle, well known to chemical engineers, as a means of avoiding the characteristic roughness in power met with in BWR's, and it has now been studied for some years both in the UK and in Italy.

From these studies and the results of US work on boiling reactors, a body of information has been built up from which it has been possible to make feasibility and preliminary design studies. The UK and the Italian (CISE) designs both use heavy water moderation and light water cooling, the British version being a modification of a design for a steam-cooled reactor. Some features of the specific designs will be given later, but the general characteristics of such systems must first be considered.

HEAT TRANSFER AND FLUID DYNAMICS

General

Spray evaporation is only one of a number of possible regimes of two-phase flow, any or all of which may be encountered in water-cooled reactors under normal or fault conditions. For stable operation, it is generally essential not to allow the system to swing over into one of the adjoining regimes, so it is important to have a clear picture of the various possible flow patterns and their inter-relationships.

The primary variable is the 'quality' of the mixture (ratio of steam flow to total mass flow), and Fig. 1 illustrates its effect by considering the behaviour of initially cold water introduced into the base of a tall tube, to the walls of which heat is applied at a fixed rate, as in a once-through boiler. The water is totally evaporated during its passage, so that the quality rises from zero to 100% steam, passing through the different regimes in turn.

In the lowest section, *A*, the water is simply increasing in temperature, and heat transfer is governed by the ordinary convective laws. In principle this represents the situation in a pressurized water reactor. When the bulk temperature approaches boiling point, sub-cooled boiling can occur near the tube walls, leading, at high fluxes, to film-boiling and so-called sub-cooled burn-out.

In section *B* net-boiling takes place, the mixture consisting of steam bubbles dispersed in the turbulently flowing water—as in a boiling water reactor; heat transfer is governed by the well established laws of nucleate boiling.

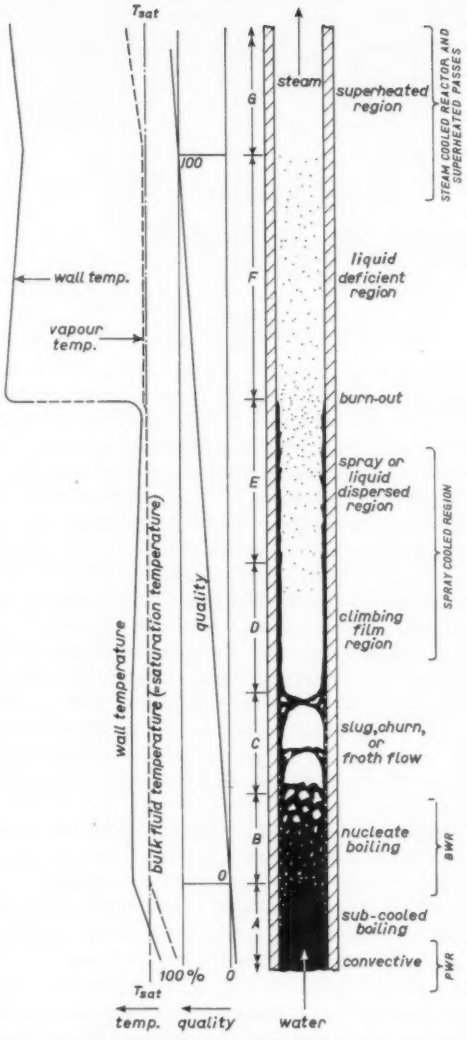
Leaving aside section *C* for the moment, we see that in *D* the steam has increased in proportion to the water to the point where it has become the continuous phase, the water having partly been displaced to the walls and partly dispersed as droplets in suspension. This is the beginning of the 'liquid-dispersed' regime, made use of in the spray-cooled reactor concept. Region *C* represents an unstable intermediate condition in which the phases are becoming inverted, from continuous-phase water to continuous-phase steam, giving 'slug flow', 'churn flow' or 'froth flow'.

In region *E*, the steam velocity has become high enough for the resulting shear forces to begin to disrupt the surface of the film, yielding a marked increase in the proportion of spray; in fact the bulk of the water now flows in this dispersed form. There is not a sharp boundary between *D* and *E*.

Up to and including this regime, the heat transfer coefficients have been very high, and the tube wall temperature has not, therefore, been much in excess of the saturation temperature of the water. Eventually, however, a point is reached (depending on the heat flux) where the film on the wall vanishes, and the heat transfer coefficient falls abruptly, leading to a sudden very large increase in wall temperature—the burn-out point.

Above this point, region *F*, there is simply a dispersion of droplets in the steam—the 'liquid deficient' region—which changes over to dry or superheated steam in region *G*. This is the condition in a steam-cooled reactor—or the superheating passes of a water-cooled reactor. In both *F* and *G* heat transfer occurs by the normal convective process.

Some of the advantages of the spray-cooled region can now be seen. Although heat transfer is at least as good as in the boiling region, there is only a small hold-up of water, the film being of the order of 0·005 in. thick, with consequently only a small effect on the required fuel enrichment; and large relative variations in the holdup of water will, with the appropriate design, have only a small effect on the reactivity. To avoid region *B*, and the erratic and little understood region *C*, steam and water are separately injected at the inlets of the fuel channels in the appropriate proportions.



Regimes of two-phase flow (Fig. 1)

Although the illustration shows flow in a pipe, under practical reactor conditions the mixture has more often to flow in the interstices of a bundle of rod- or even plate-shaped fuel elements; but it has been found that the same regimes apply (with films climbing up the outsides of the elements), though there are complications due to the local variations in spacing between the elements.

The spray-cooled regime

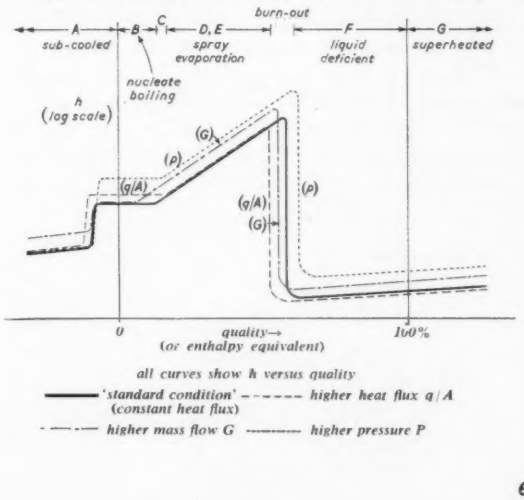
The governing factors in the utilization of spray cooling are: the limits of the regime (burn-out), heat transfer coefficients, and pressure drop. Considerable advances have been made in recent years in analysing the regimes hydrodynamically, but there are still several incomplete links in the chain. For example, in the absence of spray it is now possible (*2, 3, 4*) to predict the film thickness quite accurately from the pressure drop, knowing the flows and the liquid properties; and from this the heat transfer coefficients can likewise be calculated (if rather less accurately). But the wave motion on the film (and thus the surface roughness) is not sufficiently well understood to allow the pressure drop itself to be predicted accurately. Further complications arise in the spray region; here the film flow becomes greatly reduced at the expense of spray, but the proportion of entrained water cannot yet be predicted analytically, and the 'gas' density and viscosity are affected in a manner only partially understood. There is continual deposition of droplets on to the film, which is balanced by the disruption of the film into spray, and this again must influence the heat transfer at high mass flow rates. Lastly, much remains to be understood in the final break-down of the film at burn-out, which is probably closely connected with the wetting angle of the water and other surface tension effects.

For design purposes, therefore, we have at present to fall back on semi-empirical correlations. For pressure drop and heat transfer these are based on a quite large accumulation of experimental evidence, and are satisfactory if not extrapolated too far beyond the range of the experimental conditions for which they were devised (which generally includes only tubular or annular geometries). For burn-out there are empirical correlations arising out of studies of boiling water systems: a large proportion of these published burn-out data (*5, 6*), derived for tubular, rectangular and annular geometries, refer, in effect, to fault conditions where the excessive evaporation has driven the system into regimes *D*, *E*, and finally *F*; by appropriate selection of these data correlations have been derived (*7*) which relate to the spray-evaporative regime. No data, however, have been published relating to bundles of rod-shaped elements.

Details of the various correlations will not be reproduced here—design methods based upon them are available elsewhere (*8*)—but it will be useful to indicate some of the functional relationships and typical figures.

Heat transfer coefficients under spray cooling are so high (of the order of 20,000–40,000 Btu/h ft² °F at 1000 lb/in²) that the precise values become of little consequence; temperature differences at heat fluxes of, say, 100 W/cm² are only of the order of 10°F; Fig. 2 shows the way in which heat transfer coefficient h varies with quality (*9*). It is constant in the nucleate boiling regime, rises steeply under spray evaporation, and falls abruptly at burnt-out. At high pressures h is raised higher still and so is the quality at the burn-out point—thus widening the available operating range of quality (although at higher pressures still, above about 1000 lb/in², the quality at burn-out is lowered); raising

Variation of heat transfer coefficient with quality (Fig. 2)

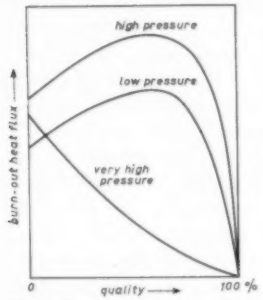


the heat flux likewise reduces the quality at burn-out, and Fig. 3 illustrates the interaction of these three variables. At very low heat fluxes region *F* contracts almost to vanishing point.

THERMODYNAMICS AND STEAM CYCLES

The main advantage of reactor systems which allow net generation of steam in the reactor core is the attractive possibility of using the steam directly in a condensing turbine-generator set. The direct use of the steam allows large savings in the heat exchange equipment and reduces the comparatively complex primary and secondary cycle system to a unit cycle comparable with conventional power station practice.

Three steam cycles have been proposed for use with the wet-steam spray-cooled reactor concept. These are shown in

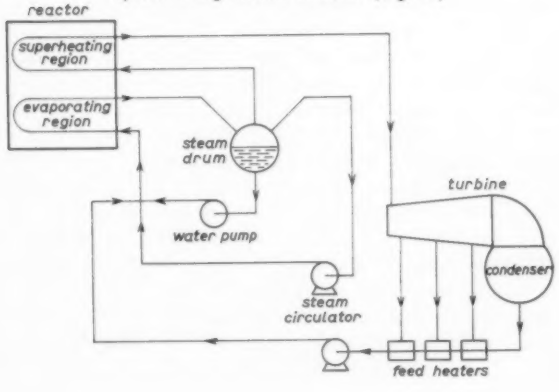


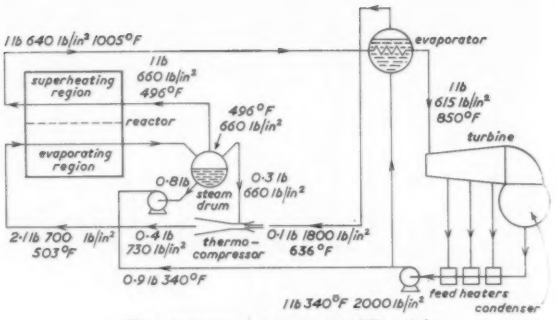
Variation of burn-out heat flux with quality and pressure (Fig. 3)

diagrammatic form in Figs. 4*a*, *b* and *c*. In the first cycle, a water/steam mixture is fed to the fuel channels in the evaporating region of the reactor, whence the two-phase mixture emerges with an increase in steam content. It is passed into the steam drum where the steam is separated from the water and divided into two streams; part is recirculated to the base of the reactor by means of a steam blower, there to re-entrain reheated condensate from the turbine feed heaters, and the remainder (equivalent to the steam actually raised in the evaporating channels) is superheated in separate fuel channels in a second region of the reactor core and passed to the turbine. This thermodynamic cycle is similar in some respects to the Loeffler cycle (*10*) used in a number of conventional power stations. It suffers from the disadvantage of requiring steam circulators—items of relatively high capital cost which are difficult to maintain with an active circuit, especially under load.

In the second cycle (Fig. 4*b*) the steam circulator is replaced by a thermocompressor (as has been suggested in a recent steam-cooled reactor resign (*11*)). To operate the

System using steam circulator (Fig. 4a)





Thermocompressor system (Fig. 4b)

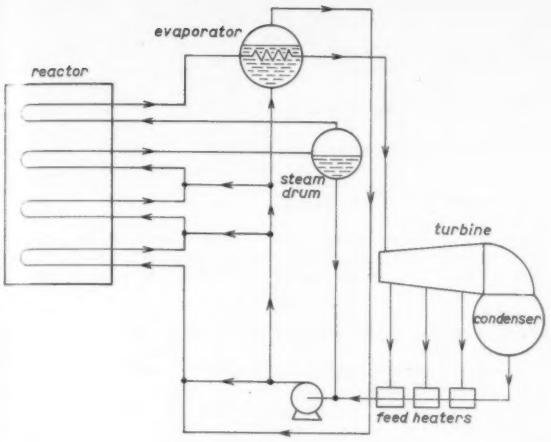
thermocompressor a supply of steam at 1800 lb/in² is required, and this is obtained from a small steam generator which abstracts part of the superheat of the main steam going to the turbines. Approximately one-tenth of the turbine condensate is diverted in this way, the rest passing to the reactor where it is joined by the steam circulated by the thermocompressor. In principle this cycle provides a simple way of saving blower power and avoiding moving machinery, but it has certain inherent limitations; it can only be applied where a high reactor outlet temperature and low pressure are employed, and the conventional thermocompressor or ejector performs satisfactorily only over a limited range of flows. It does not normally operate under the conditions here envisaged, where the working fluid loses a large amount of its kinetic energy, and more information will be required on its design, operation and control, especially with regard to stability.

The third cycle (Fig. 4*c*) is at present the most favoured for use with this reactor concept. This is a multipass system. At each pass, water and steam are injected into the fuel channels from which they emerge with a diminished ratio of water to steam: this is restored by the injection of more water before feeding to the next pass. Steam for the first pass is obtained from a small generator making use of a part of the outlet steam superheat, and the mass-flow increases considerably at each pass. Excess water is separated and recycled before the steam is passed to the superheating channels of the reactor. This cycle has the advantage that no moving parts are used in the primary circuit apart from boiler feed pumps.

REACTOR PHYSICS

Light water/steam mixtures have both neutron moderating and neutron absorbing properties, the effects varying directly with the density. Consider the case of a spray-cooled reactor of the pressure-tube type moderated by heavy water. With high values of the ratio of volumes of heavy water to uranium oxide fuel (V_{D_2O}/V_{Ox})—in the range, say, 15–20—almost all the neutron moderation is carried out by the heavy water and the light water acts almost entirely as a parasitic absorber. With lower values of V_{D_2O}/V_{Ox} the light water begins to play a part as a moderator also. Consequently, although at high V_{D_2O}/V_{Ox} ratios the enrichment needed rises fairly rapidly with coolant density, with a markedly undermoderated system the change is less rapid.

To gain the maximum advantage from the viewpoint of low initial enrichment, the spray-cooled reactor should be



Multipass system (Fig. 4c)

designed with a large V_{D_2O}/V_{Ox} ratio, say approximately 15, with a coolant to fuel volume ratio of approximately 2. However, in the event of a partial or complete loss of coolant in the primary circuit, the removal of the neutron absorbing steam-water mixture will allow an increase in reactivity of the system. The magnitude of this increase will be dependent upon the type and size of the reactor, the steam-water density, the geometry of the fuel channel and lattice, and a number of other factors. Considering an example, for a heavy water moderated reactor 15 ft in diameter operating at 1500 lb/in² with a mean coolant density corresponding to 30% by weight, a reactivity increase of approximately 1% may be expected for a complete loss of coolant.

Even this amount could generally be accommodated by the temperature coefficient of the fuel plus the control rods but the problem may be reduced and possibly eliminated by undermoderation. However, the price to be paid for this will be an increase in the initial enrichment required and the practical solution will be a compromise depending upon engineering and economic considerations.

CONSTRUCTION MATERIALS

The two regions of the reactor present different problems to the fuel element designer and metallurgist. In the evaporating zone, immediately the high velocity steam and water mixture enters the fuel channel, thin relatively slow-moving films of water form on all surfaces, while a heavy dispersion of micro-droplets fills the remainder of the cross-section, travelling at about the same velocity as the steam; surface temperatures are only a little above saturation. In the superheating region the steam behaves virtually as a gas though initially containing a small proportion of residual spray, and the temperatures are, of course, substantially higher.

So far as the fuel or fertile material is concerned, the choice is very limited, because steam reacts vigorously with uranium and thorium metals, and many of their alloys are severely attacked. Both uranium oxide (UO_2) and thoria (ThO_2), however, appear to be stable in high-temperature steam and are therefore a suitable first choice.

In the evaporating zone, the excellent heat transfer characteristics of spray cooling ensure that fuel element surface temperatures are always kept below 350°C under normal operating conditions, and it is hence possible to consider the use of certain non-ferrous alloys as canning and structural materials; the zirconium-nickel-iron alloys zircaloy-2 and zircaloy-3 appear to be suitable for operation for extended periods up to this temperature. It may be noted that should there be a failure of water flow to any channel the flow of the steam alone will keep the temperature down to the region of 450–600°C, which zircaloy may be expected to withstand for a short period.

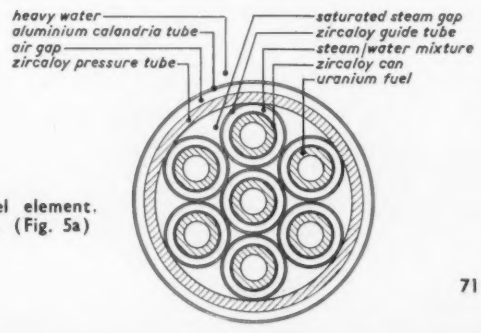
The fuel channel wall, searating the steam/water mixture from the heavy water moderator, would be designed to act as a pressure tube to contain the full coolant pressure, allowing the heavy water to stay at substantially atmospheric pressure and temperature. The pressure tube is required to operate at approximately 300°C, so again the zirconium alloys can be considered as the structural material.

The fuel channel of the superheating zone, on the other hand, would be required to operate under the following typical conditions—an inlet steam temperature of 320°C, an outlet steam temperature of 570°C and a maximum fuel element surface temperature of 670°C with the possibility of hot spots at 750°C. Whilst uranium oxide is still suitable as the fuel material, no non-ferrous canning materials are capable of withstanding steam at such temperatures for any length of time. Only the austenitic stainless steels have been proved for use under these conditions and experience with conventional steam plant has shown their excellent suitability, provided certain precautions are taken. Most suitable are 18/8/1 stainless and 25% Cr–20% Ni alloy steel. However, stainless steels are subject to transcrystalline stress corrosion in steam and, under conditions where the degree of superheat is small and trace quantities of chloride ion are present, failure may occur due to cracking. At present the possibility of stress corrosion cannot be definitely eliminated and it is inadvisable to allow operating temperatures to come within 50°C of the saturation condition, where there is the possibility of local concentration of chlorides.

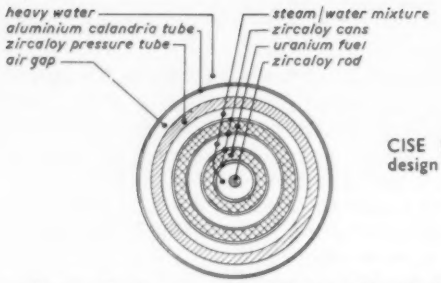
Although the outlet steam temperature is some 570°C it is possible to design the fuel element, using liner tubes, so that the metallic pressure tube is not exposed to steam above 320°C, and then zircaloy-2 may again be considered. As an alternative to the expensive zirconium alloys, the aluminium-nickel-iron alloys are being developed. However, further testing and development are required before these materials can be recommended for use in the construction of a reactor in which the pressure tubes would be required to have a life-time of some twenty years.

For the external circuit, the choice is wider. For one of the reactor designs cited later the steam outlet temperature is about 550–600°C, and experience with conventional steam plant under similar conditions indicates that low alloy steels (1% Cr–0·5% Mo) may well be suitable.

It has been suggested that under spray-cooling conditions deposition of salts or suspended material may occur upon the primary heat transfer surfaces in a reactor system, owing to the evaporatio. of droplets hitting the hot



CISE fuel element, design A (Fig. 5a)



CISE fuel element design B (Fig. 5b)

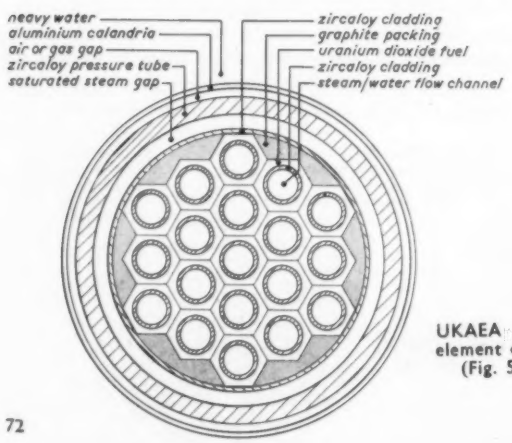
surfaces. In the authors' opinion this mechanism only occurs in the liquid deficient regime, i.e., above the burn-out point, the regime of high heat transfer (convective regime) being characterized by the presence of a thin protective film, and evaporation takes place only on this free surface. Work carried out in the USSR (*12*) on the deposition of soluble salts on heat transfer surfaces of high pressure boilers, tends to support this view; in experiments at high flow-rates, corresponding to a mean coolant velocity of 100 ft/s, the appearance of deposits on the pipe wall was observed only at steam qualities greater than 70%. Below 70%, deposition was not observed even at heat fluxes above 300,000 Btu/h ft².

The induced radioactivity and radiation chemistry problems associated with two-phase cooling will be essentially similar to those associated with the US boiling water reactors, and not likely to offer any major difficulties.

SPECIFIC DESIGNS

Two teams are investigating the possibilities of spray cooling in heavy water moderated power reactor systems. In Italy, the CISE Laboratories in conjunction with Ansaldo, the Italian engineering firm, and NDA, are studying the feasibility of the concept for a power reactor, under a contract within the framework of the US-Euratom agreement. In the UK, a limited study of a small reactor experiment has been carried out by the Design and Engineering Group of the UKAEA at Risley. An experimental programme on the heat transfer and fluid dynamic characteristics of the system has been under way for some time in the Chemical Engineering Division laboratories of the Research Group of the UKAEA at Harwell, and CISE are also supporting their studies with extensive experimental work.

The Italian design concept (*13, 14*) is based on a natural uranium metal fuelled heavy water moderated system. A pressure-tube design has been selected and the fuel is a 98% uranium–2% zirconium alloy. The reactor operating pressure is 800 lb/in² with a steam quality at the inlet to the fuel channel of 20% by weight steam, and an exit



UKAEA fuel element design (Fig. 5c)

TABLE I *Fuel element details*

FUEL ELEMENT DETAILS	CISE design *A*	CISE design *B*	UKAEA design
Power output from centre channel, MW	1·36	1·67	2·5
Maximum heat flux, Btu/h ft²	363,000	469,000	370,000
Mass velocity of coolant, lb/h ft²	$0·7\times10^6$	$1·0–1·3\times10^6$	$1·1\times10^6$
Inlet quality % by weight steam	20%	20%	15%
Outlet quality % by weight steam	60%	60%	50%
Pressure drop along channel, lb/in²	7·65	14·7	13% pass
Pumping power as percentage of thermal output	0·67%	1·3%	2·75%
Rating of fuel (maximum), MW/tonne	25	25	30
Fuel life-time (expected), MWd/tonne	6800	—	6000
Maximum fuel temperature, °C	400	400	2100
Core diameter, ft	20	18	9·5
Fuel channel pitch, in.	8	8·3	9·3
Number of fuel channels	660	481	64
Axial form factor	1·302	1·249	~ 1·5
Radial form factor	1·263	1·159	1·88
Reactor operating pressure, lb/in²	800	800	700

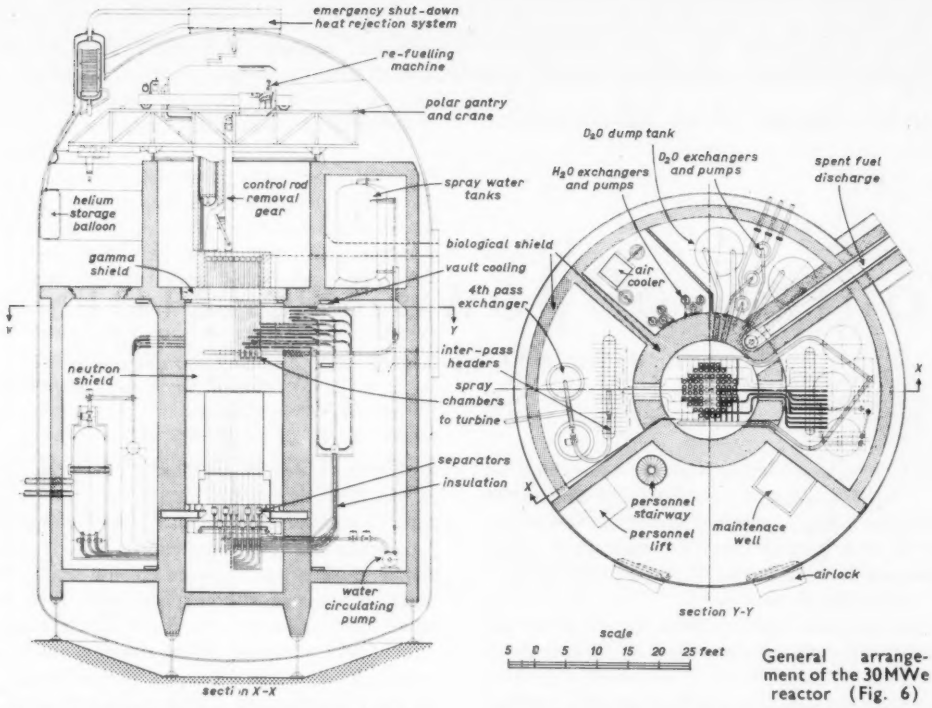
quality of 60%. The reactor has a thermal power output of 714 MWt. Zircaloy has been chosen for both the fuel canning material and the pressure tube. The heavy water is contained in an aluminium calandria separated from the pressure tube by an insulating air gap which allows the heavy water to remain cool (60°C).

The thermodynamic cycle used is very similar to that shown in Fig. 4*a* using steam circulators, with the single pass through the reactor but no super-heating region. After the separation of water in the steam drum the saturated steam passes direct to the turbine, which would be designed for water extraction between the high and low pressure stages.

Both the core and the fuel elements have some unusual design features for a power reactor. The core, which is 11 ft 6 in. long, has an inner D_2O reflector 20 in. square, in addition to the 31½ in. axial reflectors of D_2O at top and bottom and a 40 in. graphite radial reflector, so giving an unusually flat radial flux distribution.

Two designs of fuel element have been investigated. These are shown in Figs. 5*a* and *b*. The first consists of a cluster of seven hollow fuel rods clad in zircaloy-2—each surrounded by zircaloy tubes to guide the water/steam mixture. The tubes touch one another and also the zircaloy-2 pressure tube. The spaces between the guide tubes are filled with dry saturated steam. A metallurgical bond is formed between the fuel and the 0·028 in. thick can. The fuel rating is 25 MW/tonne and the expected life-time 6800 MWd/tonne. Further details of the fuel channel are given in Table I. The critical size calculations for the power reactor employing this fuel channel indicate a core diameter of 20 ft with some 660 channels on a square pitch of 8 in.

The second design of fuel element, which is the preferred alternative, is shown in Fig. 5*b*, and consists of two concentric annuli of zircaloy-canned fuel with three concentric annular coolant flow channels and a solid central zircaloy rod. Originally there were a number of radial spacers to subdivide the flow channels, because data from MIT had indicated a close inverse dependence of burn-out flux on channel hydraulic diameter. However, after heat transfer experiments and careful interpretation of the



General arrangement of the 30 MWe reactor (Fig. 6)

US burn-out data, the engineers at CISE came to the conclusion that burn-out heat flux was only slightly affected (and in the opposite sense) by changes of flow channel diameter, the radial spacers were therefore omitted.

Details of the fuel channel are given in Table I. With this second more highly rated design of fuel element, the maximum heat flux of 469,000 Btu/h ft^2 allows a minimum factor for safety on burn-out of 2·74 using the CISE burn-out correlation.

The short design survey of a spray-cooled reactor carried out by the Design and Engineering Group, UKAEA, at Risley, forms part of a larger investigation into various reactor concepts moderated by heavy water and cooled by either boiling light water or light steam.

The scheme examined was for a small power reactor or reactor experiment with an electrical output of 30 MW and a thermal output of 85 MWt developed from 64 fuel channels. The steam cycle suggested is the multipass type (Fig. 4c) with three evaporative passes and one superheating. The cycle was based on turbine stop valve conditions of 615 lb/in^{2}a and 850°F. The main details of the fuel channel are given in Table I.

The reactor core is some 9 ft 6 in. in diameter and 11 ft long. Top and bottom reflectors of heavy water each 12 in. thick and a light water radial reflector are provided. Uranium dioxide fuel would be employed with a maximum rating of 30 MW/tonne and an expected life-time of at least 6000 MWd/tonne.

As with the CISE design, the fuel elements suggested for the UKAEA reactor were influenced by the lack of information on spray evaporation with complex fuel elements of the multi-rod cluster type in a circular channel. Attempts were made, therefore, to arrange the fuel so that the resulting coolant passages resembled the simple shapes already tested. One of the fuel elements considered (see Fig. 5c) was the inverse of a rod cluster, i.e. it is virtually a large solid element perforated by coolant tubes. The fuel itself is made of hexagonal uranium oxide pellets stacked round nineteen zircaloy coolant tubes, the voids being filled with graphite to fit the containing tube as shown. Water at the saturation temperature would be injected into the steam through orifices below the fuel element and separated from the steam after the fuel element in each evaporative pass. For the fourth pass, in the superheating section, stainless steel sheathed fuel elements of the multi-rod cluster type would be employed. Stainless steel sleeves around the fuel element ensure that the zircaloy pressure tube is not exposed to superheated steam at high temperature.

Fig. 6 shows a general arrangement drawing of the 30 MWe reactor, using downward flow of coolant.

The designs reproduced above do no more than present a preliminary picture of the reactor concept. Much further experimental and detailed design work remains to be carried out before an acceptable reactor design emerges, and so far the system has not been economically assessed. Nevertheless, sufficient has been done to indicate that it is potentially a very attractive system which warrants further study.

Acknowledgments

The authors are indebted to Professor M. Silvestri for permission to reproduce Figures 5*a* and 5*b*, and for other data.

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The concluding article considers overall control and the performance required of an automatic control system

Control of power reactors—2

by R. H. CAMPBELL, B.Sc., A.M.I.E.E., *Assistant Chief Engineer, Reactor Engineering Branch, UKAEA, Risley*

IN THE LARGE POWER producing reactors being built in the UK, control is effected by movement of control rods into the core. The characteristics of these rods is described as black or grey to neutrons, depending on the degree of absorption, the black rod absorbing substantially all the neutrons entering its boundaries.

The absorber material used is boron and its effect (in the proportions used) is to embrittle steel, so an additional member is needed to take any load to which it is subjected. A stainless steel sheath serves both for this purpose and also to protect the boron steel against the coolant. Where rods of smaller absorption are required (i.e. grey rods), steel is a suitable material.

The control rods are used both in starting up and in running the reactor on steady load. Most of the reactivity change is taken up during start-up and in the period immediately following, to compensate for the build up of the xenon fission product poisons in the fuel during this time, and for the change in moderator and fuel temperatures. When the reactor has a negative moderator temperature coefficient of reactivity (i.e. at low fuel irradiations), the control rods have to be kept moving out to increase power level because of the coefficient's self-stabilizing effect.

The Xe-135 isotope has a high absorption cross-section and can absorb a few per cent in reactivity, the exact amount depending on the steady flux level at which the reactor is running.

On a reduction in operating power level, the rate of destruction of Xe-135 is immediately cut because the number of neutrons captured falls with the flux, whereas the rate of production of Xe-135 from the decay of I-135 is only slightly affected initially. The reactivity absorbed, therefore, rises as shown in Figure 2. A maximum is reached after a number of hours and this is followed by a reduction to a new lower equilibrium level. If a reactor is not re-started quickly after a shut-down, it may be impossible to achieve criticality until the xenon poison level approaches its original value again, i.e. after about a day, either because the rate of withdrawal of the control rods, which is specified from safety considerations, is too slow, or there is insufficient excess reactivity available to counteract the higher xenon poison level.

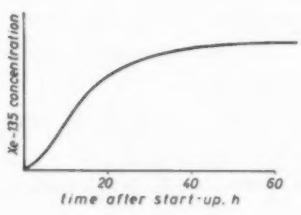
Keeping the reactor critical in face of these xenon and temperature effects requires the use of the main bank of rods. When steady conditions have been reached, only small changes have to be made. These cover the changes in reactivity occurring during steady running and in making power level changes over a limited range, and during on-load refuelling. In a large reactor, this latter disturbance may be less than the absorption effect of the grab used to handle the fuel elements.

A small number of standard control rods may be used for these manœuvres or alternatively, a group of smaller rods may be used. In a large reactor with spatial instability, this small group will also provide the stabilizing required. Whether it is considered worth while departing from the standard control rod for this purpose will depend on the extent of the depressions in the neutron flux caused by the rods, and the effects of these depressions in producing temperature cycling in fuel channels adjacent to control rods. In addition, limitations may be imposed for safety reasons on the reactivity held by this group, if they are driven by an automatic control. The type of flux depressions caused by single control rods in the axial and radial directions are shown in Figures 3 and 4.

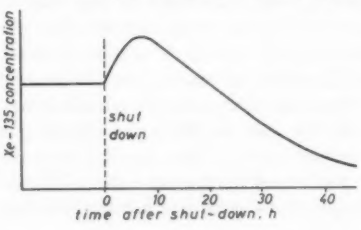
Required control system response

The main criterion on which control system performance is judged is that of attaining minimum temperature cycling of the fuel. This temperature cycling occurs both over the reactor as a whole with gross changes in reactivity, and locally in channels adjacent to the control rods because of the change in flux depression with the movement of the rods. The local cycling is minimized, as described in the previous section, by the choice of control rods. The design of the automatic system has to be optimized to keep the overall cycling as low as possible.

The disturbances take the form of ramp changes in reactivity. Since it is difficult to judge the amount of damp-



Xenon build up after start up (Fig. 1)

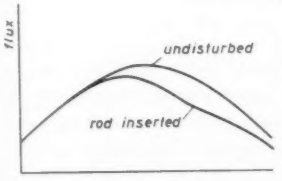


Xenon build up after shut-down (Fig. 2)

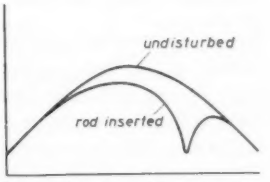
ing in a system by examination of its response to ramp functions, step inputs are normally applied in the optimization of system performance. This can be carried out on either a digital or an analogue computer but much more quickly on the latter.

The numerical approach described in the last article, in which a number of linearizations and approximations have to be made in order to reduce the work to manageable proportions, is used to determine the extent of the stability problem and to find the most promising method of attack. It is used, for example, to investigate whether phase advance alone with control on fuel temperature is likely to provide an acceptable solution; and if so, the probable time constants required.

The separate plotting of the amplitude and phase of the open loop response (the amplitude being plotted on a logarithmic scale or on a linear scale expressed in decibels) produces a very powerful method of determining the effect of various configurations of stabilizing networks. A typical



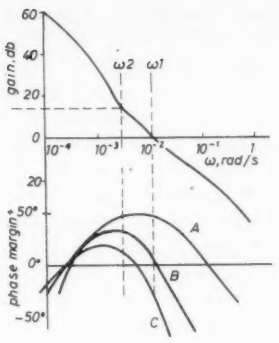
Effect of rod on axial flux shape (Fig. 3)



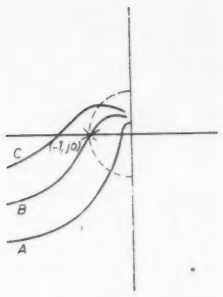
Effect of rod, partly inserted, on the radial flux shape across a diameter (Fig. 4)

response of a reactor system fitted with autocontrol is shown in Figure 5. The frequency scale is logarithmic and phase margin (180° − phase), is plotted instead of phase. A positive phase margin at the frequency at which the gain is unity (i.e. gain of 0db) indicates stability. Curve *A* of Figure 5 is the response of a stable system. Zero phase margin (curve *B*) shows that oscillations would just be maintained and negative phase margin (curve *C*) means instability. In applying these diagrams it is important to remember that they are modifications of the Nyquist diagram so that all the same rules apply. Figure 6 shows that part of the Nyquist diagram close to the $(-1, j0)$ point for the three curves of Figure 5.

The *B* system could be made stable by lowering the gain to give 0db at ω_2 (Figure 5) but even then the degree of stability would probably not be sufficient for a reactor control which ideally should have a phase margin of at least 50–60°. Matters can be improved by use of shaping functions such as phase advance. Plotted on the same type of diagram, the response of a phase advance term $K(1 + 100s)/)(1 + 10s)$ is shown in Figure 7. The dotted curve, which gives the true response differs only slightly from the asymptotjc curves (the maximum error being 3 db at the corner frequencies). It is normally sufficiently accurate to use the asymptotic response which is produced by increasing the slope of the line by 6 db/octave for each $(1 + Ts)$ term in the numerator starting at a frequency of (1/T) rad/s and decreasing the slope similarly for terms in the denominator. With the gain expressed in db, both gain and phase of the shaping function are added directly to the open loop transfer function. Curve *B* of Figure 5 is modified as shown in Figure 8 with the original response shown by a broken line. The system which was previously



Typical response of a reactor fitted with autocontrol (Fig. 5)



Part of the Nyquist diagram close to the $(-1, j0)$ point for the three curves in Fig. 5 (Fig. 6)

just oscillatory, has been given a measure of stability particularly if the gain is decreased slightly.

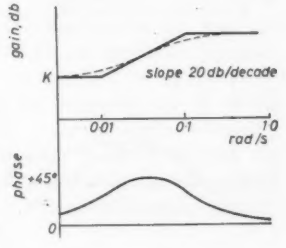
In conventional control engineering, the system is usually designed to take up its new demanded position as rapidly as possible in response to a step change in the input. Some measure of under damping is permissible to achieve a quick response. This tends to result in an overshoot as in curve *A*, Figure 9, whereas a better type of response for a reactor is shown in the other curve, which is heavily damped. The integral of the error (represented by the hatched area) is greater than with the underdamped system but this is of lesser importance than the rapid changes in fuel element temperature which result from a fast acting control.

In optimization studies for an automatic control, step changes in reactivity are normally fed in and their effect on fuel temperature examined. A typical response for a reactor with no phase advance or other stabilizing means incorporated is shown as curve *A* of Figure 10. The addition of phase advance of, for example $(1 + 100s)/(1 + 10s)$, produces the more desirable response of curve *B*. It will now be noted that some penalty in maximum temperature excursion has to be paid for the better response. For any reasonably sized reactivity step, however, this additional error is unlikely to be greater than 1°C.

In these investigations, sight must not be lost of the response to ramp functions of reactivity, such as occur during replacement of fuel in the recharging process. Here it is desirable to keep the error as low as possible and it is found that a compromise has to be made between the two sets of conditions because the error with a ramp input increases as the damping is increased.

Control parameter

Temperature has so far been assumed as the parameter by which control is effected. It is the most obvious choice because the power producing reactors are run with the maximum fuel can temperature held close to its limiting

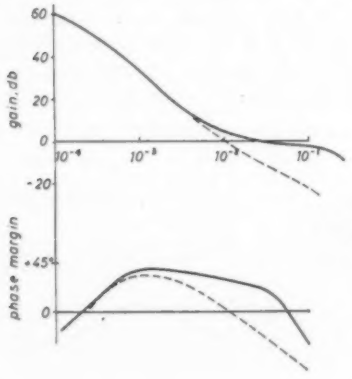


Response of a phase advance term (Fig. 7)

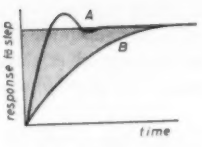
value to give maximum power. The raising of this temperature much beyond the set limit increases the rate of production of faults in the can. The use of fuel can or coolant gas outlet temperatures as the control medium has a disadvantage, however. There is a substantial lag term (measured in tens of seconds) in the transfer function relating neutron power and fuel temperature. This creates some difficulty in the obtaining of adequate stability. Control on neutron flux instead of temperature therefore eases this problem. In Figure 11, the two Nyquist diagrams of a system with control on flux and on temperature illustrate the greater stability margin with flux control. The difficulty of stabilizing a temperature control increases as the range of power levels over which the control has to operate is extended downwards; this is because the fuel temperature lag is dependent on coolant conditions in addition to the thermal inertia of the fuel. This effect is considerable; at low flow, for example, the effective lag may be seven or eight times the value given by considering only the thermal inertia of the fuel, whereas at full flow the ratio is only about three.

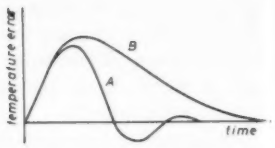
From the safety point of view, however, flux control has a number of shortcomings, which have so far outweighed its better stabilizing properties. Ultimately it is fuel can temperature which must be controlled within narrow limits. Maintaining the measured flux at a fixed value does not necessarily keep the fuel temperature constant. Variations due to change in coolant flow or coolant inlet temperature are not compensated for automatically as they are with a temperature control; the use of a thermal column outside the reactor for neutron flux measurement can result in error because of the effect of control rod movement in changing the ratio of measured to actual flux. This can vary by as much as 5% as the rods move out to cancel the effect of xenon after start up. The first of these difficulties can be overcome by setting the demanded level of flux as a nearly linear function of measured coolant flow; but the added instrumentation decreases a reliability which is already somewhat lower because of the more complex instrumentation required for flux measurement. The development of a reliable in-pile detector would go some way towards solving this and would also be required for a reactor with spatial instability unless two separate control systems were provided, one controlling the fundamental on flow or temperature, and the other controlling the zones independently on temperature.

For these reasons, control on reactor outlet gas temperature has been selected for the large reactors. If flux



Curve B of Fig. 5 modified by a shaping function, the original curve is shown dotted (Fig. 8)





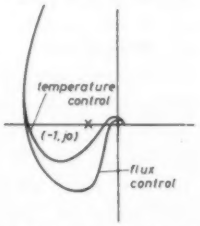
(Left) Curve A shows response when under-damped, curve B is heavily damped (Fig. 9). (Right) Reactor response, A with no stabilization, B with phase advance (Fig. 10)

has to be used in the future because of increased difficulty in attaining adequate stability in more advanced reactor designs, it is likely that a slow acting function of temperature, such as the integral of temperature error, will be added to the flux input to keep the long term control predominantly from temperature.

Outlet gas temperature has been chosen in preference to fuel can temperature because the measurement is more reliable and it is representative of a whole channel rather than one element only. The temperature difference and time lag between can and gas temperatures are small and do not, therefore, influence the choice.

Automatic controller design

The control rods used for automatic control may or may not be different from those performing the other functions. The maximum speed at which control rods can increase reactivity is severely limited for safety reasons

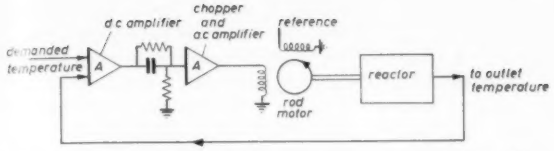


Two Nyquist diagrams showing a system with control on flux and on temperature (Fig. 11)

and their linear speed is therefore very low. A considerable proportion of the life of the main bank of rods is spent stationary and a low speed synchronous a.c. motor has been found very suitable for the drive. Speed of the rods is controlled from zero to a maximum in either direction by variation of the frequency of the motor supply. It is a simple matter to arrange for the dropping of the main control rods on a trip, by removal of all supplies to the motor. If this type of trip is used, it is essential, in order to minimize the dropping time, to keep the inertia to be accelerated small by using a low gear ratio between motor and rod; this also calls for the use of a low speed motor.

Because of the small amount of reactivity controlled by the auto system, it may not be necessary to drop the auto rods into the core during a reactor trip. The same considerations need not then apply to their drives. The arrangements for providing a variable frequency supply are rather cumbersome for inclusion in an autocontrol loop, and it is advantageous from this point of view to use a more conventional and smaller motor with low operating time lags. The motor and mechanism are normally fitted inside the pressure envelope so the choice of a smaller, higher speed motor eases the motor cooling problem but makes the gear box design more exacting, but the loads on the gears are light and the use of grease lubrication in a sealed box can provide a satisfactory answer.

Proportional controllers only have been discussed for it is considered that the use of an on–off type is undesirable



Simple schematic diagram of the control loop (Fig. 12)

because of a tendency to give more fuel temperature cycling. To prevent the system following the noise in the control signals, the incorporation of a small dead band may, however, be beneficial in minimizing fuel cycling and wear of the mechanism (see Figure 13). The extent of any such dead band is best finalized when the reactor is running.

The simple schematic of the control loop shown in Figure 12 shows a conventional phase advance network between the two amplifiers. The use of phase advance in the frequency band required (i.e. at about 0·002 cycles/s) introduces some practical difficulties. D.c. amplification has to be used if conventional phase advance techniques are employed and the high time constants cannot be achieved without very large capacitors or high impedance circuits. Care has also to be taken that, because of the amplification of the higher frequencies by the phase advance circuit, the second amplifier is not overloaded by noise in the incoming signals. Other methods of obtaining the same results are available which make use of only a.c. components and the use of such a system may well be preferable.

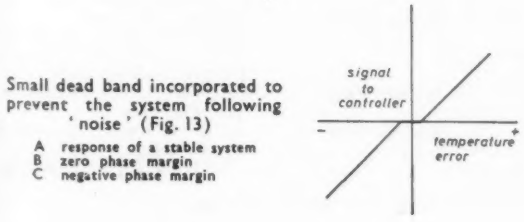
Automatic start-up

In an experimental low power reactor, a substantial dividend is to be gained by cutting down the time taken to start up the reactor, because of the number of times start up and shut down occur for experimental purposes. But in a power reactor, particularly with on-load refuelling, start up occurs only after a reactor trip or after the infrequent periods of maintenance. The trip instrumentation is designed to keep the number of spurious trips to a minimum, the total time spent in starting up is therefore such a small proportion that the additional complication of automatic start up is not justified. Its incorporation would entail too, a higher maximum rod speed in the outward direction with control of this speed from reactor period, raising additional safety problems because the maximum rod withdrawal rate is already set from safety considerations.

Station control

Power reactors are run over their whole range of operation with the maximum fuel can temperature set close to the limit and so can be looked on as constant temperature sources of power, variation in power level being obtained by changes in coolant mass flow. Overall station control may be achieved, therefore, by controlling the blowers directly from a quantity which is dependent on the demanded load, such as steam pressure at the turbine (Figure 14). Nuclear plants being built for the CEGB will operate as base load stations and there will not be required to undergo large changes in load. Since the load demanded of them will not be entirely constant, a satisfactory and reliable overall control system is a desirable feature.

Theoretically, it is possible to invert the control system described above by controlling the rods from pressure at the turbine and the blowers from the outlet temperature, but this raises practical difficulties and is not so inherently safe.

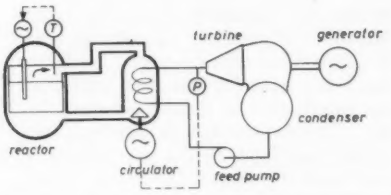


Small dead band incorporated to prevent the system following 'noise' (Fig. 13)

A response of a stable system
B zero phase margin
C negative phase margin

Reactor shut down

Ideally, a power reactor will be shut down only for routine maintenance of ancillary plant. Although the components of the system are designed to give high reliability and duplicate parts are provided, the safety of the reactor has to be protected by automatic tripping and shut downs are liable to ocur from time to time due to failures of parts of the system.



Schematic diagram of the overall control system (Fig. 14)

The tripping circuits are initiated when a trend is observed which, if allowed to proceed unchecked, would lead to damage to one of the fission product barriers. For example, an increase in the main tripping parameter—fuel can temperature—means that the fuel temperature is also higher, giving more diffusion of fission products to the interspace between fuel and can and increasing the tendency to faulty fuel can production.

To shut the reactor down quickly, if, for instance, the power supply to the circulators has been lost and this is causing fuel can temperatures to increase, the control rods must be inserted rapidly. In the UK power reactors, this is accomplished by allowing the rods to fall freely into the core. If the design were such that the rods were inserted from the side or from the bottom, they would have to be driven in, with power derived from some energy storage device, instead of gravity.

As an additional safeguard, a further shut down system, with absorber in a non-rigid form, is sometimes fitted. Ideally, the shut down absorber should be of gaseous or liquid form to ensure entry into the core, but there are practical difficulties in retaining these forms in the core. Stainless steel balls with about 1% boron have found most general use in this application.

The rapid shutting down of a reactor following the dropping of the rods results in fast changes in the fuel can temperature and in the rapid loss of supply to the grid. Both are undesirable features which can be alleviated to some extent by incorporation of automatic run in of the control rods under power at tripping levels somewhat below those which cause the rods to drop. Should the trip be caused by some relatively minor fault, the operator then has a chance to correct it and get the reactor quickly back on power again.

This review of recent advances includes a country by country survey of progress, economic studies and designs

Nuclear merchant ship survey

by J. SPENCER BURKETT, FLA
Assistant Editor, 'Nuclear Power'

GENEVA 1958 revealed that the three years between conferences had seen considerable progress in nuclear ship propulsion; dreams and plans had matured to practical designs. Whilst the *Savannah* details (*1*) summarized information already known, in giving the Lenin (*2*) paper, the Russians revealed for the first time the advanced state of their technology. It was clear, however, that, although the USSR and USA held a several years lead over the rest of the world, other leading maritime nations were making serious attempts to close the gap. Japan submitted designs for a 30,000 dwt 180 MWt submarine tanker (*3*) and a 20,000 ton emigrant ship (*4*) powered with the same PWR core and coolant characteristics as the tanker. The French contribution (*5*) reported the results of a two-year study on the application of the PWR, BWR and GCR systems to a 40,000 ton vessel of 20,000 h.p., but no evaluation was made at the time. Views from the UK, represented by the British Shipbuilding Research Association (*6*) and the UKAEA (*7*) indicated doubt about advantages to be gained from nuclear propulsion but both agreed that, below 20–30,000 s.h.p., such plant was not economically attractive.

Since Geneva, activities have been intensified; although no further nuclear merchant vessels have reached the construction stage, many more detailed design studies have been made, particularly in Europe. The second German Conference on Nuclear Ship Propulsion, held in November last year at Hamburg, was attended by some 750 delegates, representing fourteen countries—twice as many as the first conference two years ago (*8*). No new technical data came to light but it was an occasion for extensive discussion on practical feasibility and economics of established principles. The Philadelphia Nuclear Ship Conference last April, sponsored by the Atomic Industrial Forum in cooperation with the USAEC and the Maritime Commission, followed similar lines, and dealt extensively with economic evaluations and problems of safety and liability. With the coming sea trials of *Savannah* and her prestige voyage to the world's principle ports, these latter problems have been the subject of very close examination by the UK Government, the International Atomic Energy Agency and, most recently, by the Intergovernmental Marine Consultative Organization at its London Safety at Sea Conference (*9*).

In Britain, interest is now focused on the two reactor systems considered the most promising—the indirect cycle boiling water reactor and the organic moderated reactor.

In Western Germany, five groups are working in the field of nuclear marine propulsion. The one that has made the most headway is the Gesellschaft fur Kernenergie Verwertung in Schiffbau und Schiffahrt mbH, GKS, a Hamburg company constituted from 33 firms representing a wide range of German industrial and financial interests. It is mainly interested in OMR application and preliminary design work, which was done by the joint US-German company 'Interatom' and largely financed with government help (£125,000), has now been completed. Based on an Atomics International design, the Hamburg project calls for 10,000 h.p. to power a research ship, the purpose being to gain experience rather than build a tanker that would be economically competitive. The original plan was to instal the reactor in the 16,000 ton tanker, the *Esso Bolivar*, but since the conversion cost (£M1·8–2·5, including reactor) was estimated to be £500,000 less than the construction cost of a new vessel, a new 15,000 ton tanker is planned that will not only be used for the Interatom OMR, but also for the BWR of AEG and the Siemens PWR, one after the other. Construction is scheduled to start in the summer of 1961 with completion by 1963 (*11*).

Siemens-Schuckertwerke AG, working with the shipbuilding company Howaldswerke Hamburg AG, are concentrating their studies on a 70 MWt reactor, half the cost of which (£128,000) is coming from the Federal Ministry. The Allgemeine Electrizitats-Gesellschaft, AEG, a licensee of the General Electric Co. and Deutsche Werft of Hamburg, is working on BWR type reactors, principally of 60 MW output. In the gas cooled field are Brown Boveri-Krupp AG who, together with AG Weser of Bremen, intend to build a high temperature gas cooled reactor, and the firm of Deutsche Babcock and Wilcox, in association with Blohm and Voss, who have a 52 MWt design. Other work is being carried out at the Hanover Technical College under Dr. K. Illies, with particular emphasis on gas-cooled systems (*12*).

In France, the three feasibility studies briefly mentioned at Geneva

UK DESIGN TENDERS

	July 29, 1960	*Galbraith design 1959*
Nuclear Power Group (AEI-John Thompson and US General Electric)	Indirect BWR	82 MW direct BWR 547°F 1000 lb/in² at turbine
Mitchell Engineering / Fairfield Ship.-Combustion Engg.	Indirect BWR	156 MW indirect BWR 496°F 635 lb/in² at turbine 180 MW PWR
Babcock & Wilcox	Indirect BWR	447°F 410 lb/in² at turbine
Hawker Siddeley	OMR	56 MW OMR 710°F 465 lb/in² at turbine
English Electric-Atomics International	OMR	none

were handed in to the French Atomic Energy Commission early in 1959. Société Alstom and the Société des Forges et Ateliers du Creusot were responsible for the boiling water project; a pressurized water design was given to the Société Alsacienne de Constructions Mécaniques; while the Indatom group studied the graphite-moderated, gas-cooled reactor. The last concept was selected and the French authorities decided to develop a land prototype at Cadarache where the same plant could be used for experiments with different types of core, liquid coolants and moderators.

Dutch interest is centred on the PWR, and both the Stichting Kernvoortsturving Koopvaardijschepen group, SKK, and the Reactor Centrum Nederland, RCN, have projects underway. SKK, a foundation composed of shipowners, shipbuilders, the Delft University, the Foundation of Applied Physical Research and RCN, proposes to install a PWR (probably American) in an existing 16,000 ton tanker. Use of this plant is not envisaged for propulsion but merely to power auxiliary services while at sea. RCN is separately engaged on a 60 MWt design with construction scheduled to start in 1963 for operation by 1965/66.

Development of nuclear propulsion in Denmark is the responsibility of Danatom, an association of some 50 firms. Their current design Alpha, a PWR project, envisages a 65,000 ton tanker that will operate alongside two conventionally powered ships, diesel and oil fired, to facilitate comparative studies to be made (*26*).

Pressurized water systems are also favoured in Italy where Ansaldo and Fiat are studying the application of a 74 MWt reactor to a 70,000 ton tanker, with the reactor likely to be built under a Westinghouse licence. Cantieri Riuniti dell'Adriatico, Italy's second largest shipbuilders, may also enter this field as they have a 10-year collaboration agreement with Babcock and Wilcox of the US.

The main interest in nuclear propulsion units in Norway and Sweden lies in the boiling water system. The Rederiatom group, composed of 19 Norwegian shipowners and the Institutt for Atomic Energy, IFA, is making preliminary design studies on an indirect cycle. The Swedish Götaverken Shipyard design is for a 65,000 ton tanker using a direct cycle. Kockums, who have already conducted tanker evaluation studies into the various concepts, seem to favour the BWR. The advanced gas cooled reactor is not being ignored; it is receiving the attention of both the shipping and engineering firm, Johnson Lines, and the turbine firm Laval-Ljungström, as well as the Swedish Shipbuilding Research Foundation.

Twenty designs have so far been put forward in Japan, by independent

MARINE REACTOR STUDIES*

	GROSS OUTPUT, MWt	FULL POWER, s.h.p.	CONTAINMENT core (i), reactor vessel (ii), containment vessel (iii)	FUEL type (enr.) cladding Burn-up(MWd/t)	COOLANT pressure (lb/in²g) temp. In, temp. Out (°F) flow (lb/h)	STEAM pressure (lb/in²g) temp. (°F) at turbine flow (lb/h)
PWR						
Combustion Engineering for USAEC 1960 (*25*)	82	30,000	(i) 52 × 44·8 in. (ii) 34 ft (d.) × 48 ft	UO_2 (5·4%), ss, 13,000	1985 Out 620 6 × 10^6	600 600 238,300
Danatom 'Alpha' 1960 (*26*)	83	25,000 –27,500	(i) 53 × 59 in. (ii) 7 ft 3 in. (d.) × 19 ft (5 in. thick) (iii) 38 ft (d.) × 1·5 in.	UO_2 (4·5%), ss, 8160	1574 500 (average) 66°F (rise I–O)	426 451
BWR						
Direct cycle US Gen. Elec. prel. design Dec. 1958 (GEAP-3088)	60	22,000	(i) 56·9 × 66·5 in. (ii) 7 ft 6 in. (d.) × 30 ft (3·625 in.–1250 lb/in²g) (iii) 39 ft (d.)–160 lb/in²g	UO_2 (2·1%), Zr-2 (0·33 in.) 10,000	1000 Out 546 5·412 × 10^6	980 546 192,718
Direct cycle US Gen. Elec. April 1960 (*28*)	78·5	30,000	(i) 60 × 60 in. (ii) 8 ft (d.) × 27 ft (iii) 50 ft high	UO_2 (3·1%), ss (0·018 in.) 13,200	1000 Out 546 255,480	980 546 233,230
Indirect cycle Westinghouse April 1960 (*30*)	77·4	30,000	(i) 69 × 58 in. (ii) 7 ft 10 in. × 27 ft (iii) 34ft × 55 ft	UO_2 (3·21%), ss 11,820	985 510 636	690 603 287,000
OMR						
A.I. May 1959 (NAA-SR—3859)	93	30,000	(i) 60 × 60 in. (ii) 9 ft 3 in. × 21 ft 1 in. (1·5 in.–300 lb/in²g)	UO_2 (3·7%), Al-Al_2O_3 10,000	50 620 675 11·3 × 10^6	450 650 219,810
Corlett & Hawthorne 1959 (*31*)	64	20,000	(i) 69 × 60 in. (ii) 9 ft 9 in. × 27 ft 6 in. (iii) 38 ft × 38 ft (1·25 in.)	UO_2 (1·6–1·8%), ss 10,000	90 563 646 4·7 × 10^6	630 620 196,910
T. H. Hannover 1959 K. Illies (*20*)	40	9,150	(i) 61 × 54 in. (ii) 6 ft × 12 ft	U (1·8%), Al 2500	81 554 590	603 486
Interatom and SKS 1960 (*30A*)	30	10,000	(i) 53 × 58·7 in. (iii) 32 ft 10 in. × 41 ft (1·15 in.)	U-3% Mo–0·1% Al (2%) AlMg	105 572 612 4·1 × 10^6	785 516 68,000
GCR	42	10,000	(i) 75 × 67 in.	UO_2 (3%), Be	N_2 456	— —
T. H. Hannover 1959 K. Illies (*20*)			(ii) 12 ft 9 in. × 9 ft 10 in.	4000	738 1200	
GEC Hartnell-Beavis 1959 (*35*)	55	20,000	(i) 72 × 72 in. (ii) 15 ft 7 in. (d.) (3·5 in.–385 lb/in²g) (iii) 44 × 37 × 35 ft (1·25 in.)	UO_2 (3%), ss (0·010 in.)	CO_2 385 500 1020	600 850
HTGCR						
General Dynamics 1960 (*33*)	53	22,000	(i) 77 × 77 in. (design pr. 1150 lb/in²g+)	UO_2 (7%)	He Out 1300-1350	

* For tables of leading parameters for earlier designs—see T. W. F. Brown (*20*) and K. Illies (*21*)

companies; all of these envisage the use of either the PWR or the BWR. The 17,000 ton emigrant ship project, discussed at Geneva, was taken up early in 1959 by the Osaki Shosen-Mitsubishi Joint Committee, who stated that construction would take 44 months and cost £M6·6 (£M1·5 for the reactor), but confirmation of the go-ahead is still awaited. The most likely development is a small experimental ship, possibly starting this year and sponsored by the Japanese Atomic Energy Commission through their Nuclear Powered Vessel Division. Other types of vessel under consideration for the first nuclear vessel are an emigrant ship and three different sizes of oil tanker. The latest move was the visit by the Japan Nuclear Ship Commission, initiated by the Japanese Atomic Industrial Forum, to Europe and USA, for the purpose of choosing the most promising type of reactor; the PWR seems the most likely choice because of the greater experience available.

With the *Savannah* project near completion, the USAEC are now anxious to get under way a second project for a 43,000 dwt tanker, ready for sea by 1964. Although the three design studies—a direct cycle BWR, an indirect cycle BWR and a PWR—have been released and evaluated, it is not thought that funds will be granted this year (*13*).

The Maritime Gas-cooled Reactor Programme, which started in early 1958, for the development of a nuclear power system holding the best long range competitive promise, is being undertaken by General Dynamics Corporation. Based on the HTGCR concept, this reactor is to be coupled with the closed cycle gas turbine. Progress to date includes research on fuel elements and heat exchangers, and the construction of a critical facility is going ahead with completion scheduled for 1964.

Cost studies

Of the many comparative cost studies made, the most comprehensive, so far, is the American-Standard project undertaken for the USAEC (*14*).

Within the framework of the assumption that all nuclear plants are fully developed and operational, the systems that offer the earliest opportunity for achieving a competitive position with conventional ships are the OMR and BWR. In view of current and expected near-term maritime practice, the report considers that ore carriers have the greatest economic potential for nuclear propulsion. Tankers and general-cargo ships, in that order, are the next best types, with passenger and passenger-cargo vessels having the least potential. Long trade route distances and high speeds favour nuclear application with the competitive position likely to improve by 1965–1970.

Benford (*15*) criticises the basis of these cost conclusions as putting nuclear power into a deceptively advantageous light. His study of attainable costs for nuclear fuel and machinery indicates that nuclear propulsion is not commercially competitive within the foreseeable future, except for the high speed passenger liner engaged on long voyages.

Roddis (*16*) also criticizes American-Standard's conclusions as somewhat misleading for they show that at least ten years of intensive development are necessary before any of the reactor

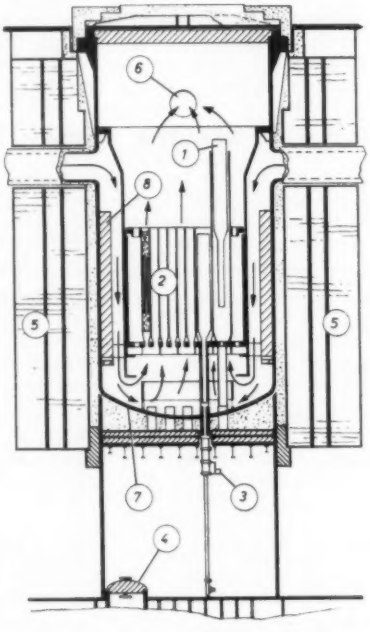


Fig. 1 Atomics International marine OMR

1. Control rods—in and out
2. Fuel elements
3. Control rod drive
4. Hatch
5. Borated H_2O tanks
6. Coolant outlet
7. Reactor vessel
8. Thermal shield

systems studied could even begin to compete with any well designed conventional ship of optimum speed. Kinsey and Bowker (*17*) reached substantially the same conclusion and considered that even if the most advantageous fuel cycle and refuelling procedures could be developed, and operating costs of the order of 0·25-3d/s.h.p.-h could be achieved, compared with 0·4–0·45d/s.h.p.-h for the conventional 65,000 dwt ship, relative savings were still inadequate to offset the present estimated capital cost of any of the systems studied. This conclusion may not necessarily apply to installations of higher power in larger ships such as high speed passenger liners.

The more recent study by the USAEC of three different types of water-cooled reactor systems (*13*), specifically considered for installation in a large tanker, more or less agreed with other critics, although it concluded that the BWR direct cycle would result in the lowest capital and operating cost. It also appeared to have the greatest potential for cost reduction in the future, when a more competitive performance could be expected from a second or third core loading with fuel fabrication costs reduced from the present $86 to $70/kgU and fuel exposure extended from 13,200 to 16,500 MWd/tonne.

Edwards (*18*) considers that power below 10,000 s.h.p. is out of the question because, instead of competing against the steam turbine plant, nuclear vessels are up against the diesel with its particularly high level of efficiency, low fuel consumption and low running costs. Small reactor systems should be the target as large reactors increase problems and costs all round. The specific weight of an oil-fired geared steam turbine system was about 160 lb/s.h.p., that for a highly enriched nuclear submarine 100–150 lb/s.h.p., but a slightly enriched nuclear merchant ship accounted for some 300 lb/s.h.p.

Design comparisons

Useful design comparisons have been made recently both in the UK and in Germany. T. W. F. Brown (*19*) reviews marine propulsion machinery developments and looks at the trend of changes in the near future. Leading parameters taken from published literature of most known nuclear ship designs, show that the PWR, the only type now at sea, gives steam conditions at the turbine of 400–500 lb/in² saturated—conditions well known to turbine designers more than 30 years ago. The BWR, operating on an indirect cycle, gives similar steam conditions but, with the direct cycle, much higher pressures become practicable, and superheating, although difficult, is possible. Although the cheapest reactor at present for marine use, the OMR may be ruled out as a long-term project.

Looking further into the future, gas or steam cooled systems offer no fundamental bar to the attainment of much higher turbine steam conditions and helium is favoured because, apart from its relatively good heat transfer properties, it has a small optimum pressure ratio.

Using almost the same published sources, Illies (*20*) makes more detailed

comparisons including studies of materials, coolants and moderators, as well as fuel cycle performance and cost relations. A table of comparative parameters is also given but it is more detailed than Brown's.

Kinsey and Bowker's study of marine reactors (*17*) was initiated to investigate the possibilities of the GCR for tanker application so that factors most influencing capital and fuel costs could be analyzed. Five reactor systems are considered. The two gas cooled designs, one graphite and the other heavy water moderated, provide superheated steam to the turbines at 850°F 615 lb/in², whilst the OMR provides superheated steam at 559°F 225 lb/in². The two light water systems, the BWR and PWR, provide saturated steam at 600 lb/in² and 450 lb/in² respectively.

Apart from any other consideration, it is clear that for containment structures, the two gas cooled designs are the largest, the AGR being also the heaviest and most expensive. Similarly, the reactor core vessels are both heavier and more costly than those for the light water and organic moderated systems.

Conklin (*21*) draws similar conclusions. Due to high pressure steam containment and material corrosion problems, the total reactor system of the BWR is 20% greater than that of the OMR. Not only is stainless steel internal cladding necessary, but a carbon steel containment shell is also required. The principal cost differences of the PWR are caused by its indirect cycle which requires additional steam generating equipment.

With the GCR, the reactor vessel is about seven times the cost of the OMR, internal fittings and graphite about ten times, and shielding some 15% more. With the same power rating the total GCR system is estimated to be 50–60% more than the OMR.

On the future use of plutonium, preliminary investigations have been made of the plutonium-burning fuel cycle. Richards (*22*) considers that it has advantages over the present HTGCR concept. With the eventual use of ceramic materials promising to retain fission products at really high temperatures, development may well lead to gas turbine application.

Pressurized water reactors

Since the US Maritime Reactor Project was initiated in September 1957, much information has been released, both by the Oak Ridge National Laboratory and Babcock and Wilcox, on various stages of the *Savannah's* progress. Apart from reports covering the primary shield design, reactor core physics and containment pressure analysis (*23*), the most pertinent at the moment are those concerned with safety analyses which aim to prove, at some length, the absolute safety of the system (*24*).

Looking towards a reduction of capital costs, Combustion Engineering recently made a study showing a number of improvements on the Savannah design (*25*). These include higher core temperatures without a concomitant increase in the primary system design pressure and an increased steam temperature, leading to improved reactor plant efficiency

The higher temperature of the primary coolant system, 620°F (Savannah —521°F), permits the use of a superheated steam cycle. Other significant advances are the zoned core which reduces the gross radial power peaking factor, and the use of the neutron rectifier type of control element which minimizes local power peaks.

Higher coolant temperatures and improved steam conditions at the turbine stop valve are also indicated in the Danish tanker design (*26*) which employs a Savannah-type PWR of 83 MWt. Danatom's comparative study, Alpha, on three tankers of 65,000 dwt showed that the relative transportation cost/ton of cargo, on the route, Persian Gulf/Cape/UK, was 60s. 6d., 47s. 2d., 42s. 8d. for nuclear, turbine, and motor tanker, respectively.

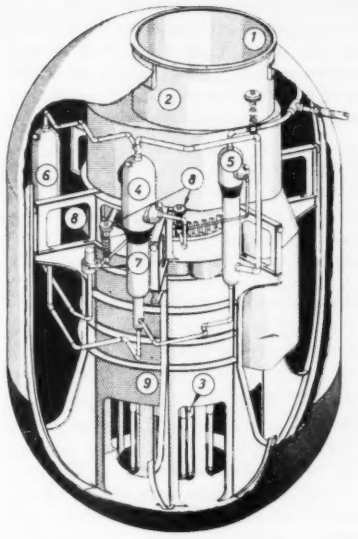
Boiling water reactors

The BWR is a leading contender for competitive nuclear power because it uses a thermal cycle of unparalleled simplicity. Permitting the coolant to boil in the core not only leads to a substantial reduction in pressure, from 200 lb/in² to 1000 lb/in² but, by natural circulation, eliminates the need for pumps and associated equipment.

In General Electric's preliminary design for a 22,000 ship study (*27*), it is shown that the propulsion system can be manœuvred from 100% steam flow full ahead to 100% steam flow astern in 10 seconds, and that the estimated maximum reactivity change due to the ship's motion could be equivalent to moving one of 21 control rods less than two inches.

To explore more fully the economic potential of this marine BWR, designs were directed towards a 60,000 dwt tanker application, and then later in 1959, towards further design improvement for use in a 44,000 dwt tanker (*28*). The result of this study was used by the AEC in its recent comparison of three water reactor types for possible prototype development in a nuclear tanker (Fig. 3.).

Although it was found that in-



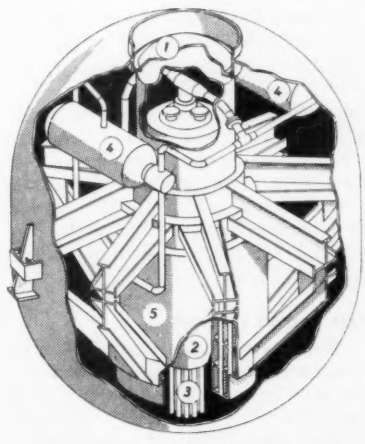
1. Hatch
2. Unloading tank
3. Control rod drive
4. Condenser-evaporator
5. Condenser-superheater
6. Subcooler-evaporator
7. Reactor feed pump
8. Main valves
9. Primary shield tank

Fig. 2 Westinghouse indirect cycle BWR

creased cycle efficiency and reduced capital costs came with the introduction of oil fired superheat, they are offset by the increased nuclear and oil combined fuel cost and by the reduction in cargo capacity due to oil superheat fuel storage.

The reactor design offered can follow a load change from 20 to 100% in 80 seconds and provision is made for by-pass dump of up to 100% steam to the condensate in the event of more rapid turbine load changes.

The Westinghouse indirect cycle design for the latest USAEC tanker project (*29*), at a design rating of 77·4



1. Hatch
2. Reactor vessel
3. Control rods
4. Condenser boiler
5. Primary shield tank

Fig. 3 General Electric direct cycle BWR

MWt, produces 415,000 lb/h of primary steam. This reaches the turbines as 287,000 lb/h steam at a pressure of 638 lb/in²g and temperature of 603°F. Although the system has a high thermal efficiency and low fuel cost, capital costs are sufficiently higher than conventional ships to make the overall economies of the indirect cycle BWR unattractive for ship propulsion, at least as far as American flag vessels are concerned (Fig. 2).

Organic moderated reactors

The direct simplicity, characteristic safety, potential economy, and ease of operation of the OMR, in spite of the present temperature limitations and thermal instability of the organic heat transfer medium, have recommended the system for maritime application.

Two designs are being tendered this month in the UK for a 65,000 ton tanker; another project is being pursued in Germany by the GKS of Hamburg for application to a research-training vessel (*30A*); in Sweden, Asea are undertaking a joint study with Kockums. In the main, these designs have been very much influenced by Atomics International who conducted its first marine study early in 1957. Its most recent study (*30*) was designed specifically for the propulsion of a 60,840 dwt Class T-7 at 30,000 s.h.p.

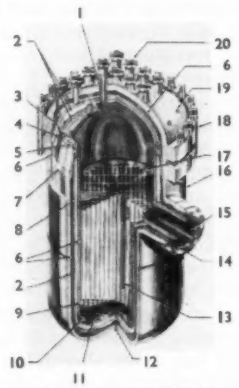
The reactor uses uranium dioxide clad in extended surface aluminium powder metal (6% Al_2O_3, 94% Al) and is capable of operating at 800–900°F surface temperature and with 14,000 MWd/ton average burnup. Superheated steam is produced at the rate of 220,000 lb/h at 450 lb/in²g/650°F. Capital cost is 50% greater than an oil-fired plant, but the cargo-hauling cost is only 20% greater and it is anticipated that many cost savings can be expected (Fig. 1).

A recent UK study (*31*), after making a comparison of families of conventional and nuclear ship designs for the routes UK–Australia and New Zealand, concludes that a 64 MW plant, enriched to 1·6–1·8% and giving a steam flow to the main engines of 160,380 lb/h, is commercially attractive. Although of advanced design, it is a practical one that could be constructed and put into operation within five or six years.

Gas cooled reactors

The Marine Gas Cooled Reactor programme in the USA, which was initiated in February 1958, began in mid-1956; a year later, feasibility studies were completed from which it was concluded that considerable development was required both on the reactor concept and the closed cycle gas turbine system. The programme also has the broader objective of expanding and advancing the GCR technology above 1300°F, for it is only at these temperatures that the closed cycle plant can compete with the steam turbine cycle in over-all efficiency (*32*) and achieve a simple, compact and lighter power plant.

The General Dynamics project aims at building a land-based prototype by 1964. For this 53 MW reactor, helium



1. aux. gas inlets; 2. thermal shields; 3. barrier bolts; 4. th. barrier flange; 5. gas passages; 6. insulation; 7. th. barrier support ring; 8. deflecting ring; 9. support plate; 10. th. barrier and core support; 11. support grid; 12. drain; 13. gas passage; 14. gas inlet; 15. gas outlet; 16. pressure vessel; 17. core cover; 18. p.v. head; 19. access to th. barrier bolts; 20. control rod thimbles

Fig. 4 General Dynamics MGCR

has been chosen as the coolant having the greatest potential. Graphite was originally scheduled as moderator material, but beryllium oxide is favoured for a substantial reduction in cost (*33*) (*34*) (Fig. 4).

GEC's 20,000 s.h.p. design analysis (*35*) shows advances over the earlier Galbraith design. New stainless steel annular fuel elements permit a power density of 270 kW/ft³ at 400 lb/in² reactor-inlet pressure, which is seven times that specified for the beryllium canned elements in the AGR. Together with other improvements in fuel element geometry, the new design represents a considerable reduction in the specific size and cost of gas cooled reactors.

Stainless steel canning is also specified in the 52 MWt reactor of Deutsche Babcock and Wilcox. This design attains an inlet temperature of 572°F and an outlet of 1022°F, giving steam at the superheater outlet of 842°F.

The gas steam reactor concept has also been studied (*36*) (*37*), primarily with the objective of putting an advanced type of reactor into a converted tanker within a relatively short time. The design considers a helium-cooled graphite moderated plant generating superheated steam at 600 lb/in² at 850°F. The use of more sophisticated loading techniques and ceramic fuel elements can bring the fuel cost down substantially.

Safety considerations

Ship reactor design is well advanced but the main consideration is reactor safety (*38*). Unlike the land-based reactor, control of design standards and of ship movement has to be on an international basis, and questions of liability and insurance become so very important (*39–41*).

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Pressure Vessel Symposium

THREE HUNDRED participants from 17 countries attended the recent symposium on reactor containment buildings and pressure vessels organized by the Department of Mechanical, Civil and Chemical Engineering of the Royal College of Science and Technology at Glasgow. Twenty-two papers by UK and American workers were presented.

A significant proportion of the papers dealt with the elastic analysis of thin shell structures. It appeared that future pressure vessels are tending towards a cylindrical shape with hemispherical ends and a corresponding shift of the emphasis of future research work on shells may be anticipated. Where loading can be accurately defined it is possible to obtain a reasonable correlation between theoretical and experimental stress distributions. Due to the present lack of precise knowledge concerning blast effects and missile penetration, considerable work is required in this field. One point made was that those working in the field of stress analysis should maintain a much closer liaison with mathematicians in order to be sure of making the best use of available mathematical tools. Furthermore, theoretical research should be initiated, where possible, on mathematically rigorous lines; when confirmed by experiment, such basic theories could then be simplified where appropriate to facilitate their translation to design data.

Because it may not be possible to use existing cooling devices and insulation techniques efficiently at the higher temperatures foreseen for gas-cooled reactors and, moreover, since maximum shell thickness would be limited by practical consideration to approximately 5 in., it was generally held that the responsibility for solving problems arising from more stringent operating conditions rests ultimately with the metallurgist. Slightly improved mechanical characteristics and more chemically pure steels can be produced by electric furnaces as opposed to steels in use at the present time manufactured by the open hearth process. It is probable, however, that the answer lies in the use of alloys, together with heat treatment. Research work in this field is already under way and further problems are being investigated, such as the effect of long-term stress-corrosion and the mechanics and chemistry of the initiation and propagation of cracks in thick plates.

A noticeable interest was shown in the use of reinforced (or pre-stressed) concrete as a containment medium but it was emphasized that its use would require highly stringent site control of concrete quality and emplacement. The most important disadvantages of reinforced concrete stem from its inability to withstand high temperature gradients and present ignorance concerning its leak tightness efficiency. Pre-stressing could overcome these to a very large degree, but it is possible that reactors housed in such containments might well have to be designed to operate at less efficient conditions of temperature and pressure. The present philosophy appears to be that concrete is an attractive medium only when the contents of the pressure circuit are not retained in the containment building. Where gases are retained under pressure, a continuous steel membrane is still advisable.

In the concluding session, attention was focused on the need for a design Code of Practice for reactor pressure vessels and containment buildings. There was general support for such a code but the need for further extensive research on full-scale structures and on the metallurgical aspects of the problem was stressed.

Medical Electronics Exhibition

THE THIRD International Conference on Medical Electronics, organized by the Electronics and Communications Section of the Institution of Electrical Engineers in association with the International Federation for Medical Electronics, is being held at Olympia from 21*27 July. The conference is expected to be larger than the first two which took place in Paris.

The Medical Electronics Exhibition taking place at the same time at Olympia will be the first fully comprehensive exhibition of its kind in the world. There is a growing interest in the specialized field of medical electronics and this is shown by the keen interest of overseas exhibitors. Some measure of the keen competition expected is the news that 12 Japanese firms are exhibiting. Other foreign exhibitors are from the USA, France, Belgium, Germany, Eastern Germany, Austria, Italy, Switzerland and Denmark. Altogether nearly 50% of the stand space has been booked by overseas firms, outnumbering the British exhibitors.

At the conference, between 100–150 papers are being read and the list includes the following subjects which are of some interest to nuclear specialists: instrumentation in medicine and biology; medical electronics in space research; isotopes and radiology; and ultrasonics and microwave radiation.

Among the English exhibitors, Nuclear Enterprises (G.B.) Ltd. are showing a whole body radiation monitor. This is their NE 8102A model (see *New Products* this month, p. 103).

English Electric Valve Company Ltd. are exhibiting high-powered magnetrons and klystrons for use in linear accelerators. They also have on show a prototype storage device whereby a method of selecting and storing a single frame of a television-type picture will be demonstrated. The storage time can be several hours and the picture can be erased instantaneously. Specific applications have not been explored but it is considered that this device will be of use in teaching hospitals and for radiologists.

The Atomic Weapons Research Establishment of the UKAEA is demonstrating seven of the instruments they have developed. These include a simple integrating gamma monitor weighing 2 lb for radiation therapy and survey work, two instruments for measuring Pu-239, and the Phantoscope—a new analyser for rapid routine radiation investigation. The equipment on show includes some completely transistorized assemblies.

Marconi Instruments Ltd. are showing their large screen X-ray Image Amplifier. This instrument has had extensive clinical trials and has been installed in several hospitals. The technique, employing television, greatly reduces the radiation dosage when detailed X-ray examinations are undertaken.

Among the exhibits shown by AEI is a model of the 'Orthotron' Series II 4·3 MeV linear accelerator. The Series II equipment has a higher energy than the Series I (4·3 MeV compared with 4 MeV) and incorporates improvements in design detail. AEI are also showing a model of the 'Orbitron' cobalt therapy equipment which uses Co-60 as the source and produces radiation equivalent to that from an X-ray tube working at three million volts.

GAS IONIZATION DETECTORS

A survey by W. R. LOOSEMORE, B.Sc., A.R.C.S., AERE Harwell

MANY DIFFERENT FORMS of gas ionization detector have been developed, and their characteristics were reviewed recently in NUCLEAR POWER (Gray and Loosemore, Feb., April, May, June 1959). The present survey supplements these articles. Each table is sub-divided into different types, which closely correspond to the different application for which the detectors are best suited. Within any sub-division the products of each manufacturer have been grouped together for convenience, although in several cases a substantially identical product is offered by several manufacturers. In many cases only average values of the various parameters are quoted since these are more helpful when selecting a detector. Thus the data should not be regarded as constituting a specification for any particular detector, although every effort has been made to ensure that information obtained from manufacturers is representative of their products. The characteristics quoted may apply only when specified test apparatus is used and when the detector is operated under fixed conditions laid down by the manufacturer, who should preferably be consulted before final choice is made. Only those types have been included for which an assurance has been obtained that the product is currently in production, or which can be put into production without further development effort. However, many items are designed for specialized applications and only very small stocks are held by the manufacturer, so that it should not be assumed that delivery will immediately follow an order.

Thanks are due to the various manufacturers for their cooperation in several discussions during the compilation of the tables.

THE FOUR MAIN TYPES

1. **Geiger-Muller counters,** for the assay of beta and gamma activity in solid, liquid and gas samples.
2. **Proportional counters.** These are available for the detection of thermal neutrons when the gas filling is BF_3, fast neutrons by recoil of protons from hydrogenous radiators, and low energy X-radiation.
3. **Mean current ionization chambers.** The electrodes may be coated with boron or fissionable material to measure mean neutron flux intensity or may be left uncoated when the response will be mainly due to gamma radiation.
4. **Pulse ionization chambers.** The electrodes are coated with fissionable material to count the fission events associated with the passage of individual neutrons.

TABLE I Geiger-Muller Counters

MANUFACTURER	MANUFACTURERS' TYPE NUMBER	OVERALL DIMENSIONS DIA. × LENGTH, cm	ANODE LENGTH, cm	CATHODE MATERIAL	(a) WINDOW/WALL MATERIAL AND THICKNESS, mg/cm² (b) WINDOW/WALL SIZE, cm	ELECTRICAL CONNECTIONS	GAS FILLING	WORKING VOLTAGE Vw, V	PLATEAU LENGTH, MIN, V	PLATEAU SLOPE MAX, %/V	DEAD TIME AT Vw, μs	TEMP. RANGE, °C	AVERAGE TEMP. COEFF. of Vw V/°C	AVERAGE LIFE, counts	MAX. RECOMMENDED COUNT-RATE, counts/min	BACKGROUND IN 2 in. Pb counts/min	GAMMA SENSITIVITY counts/min mr h Eγ≃ 1 Mev	REMARKS
1. End window counters																		Background of 1 count/min in a/c rig. *In 35 mm Pb + ¼ in. Perspex. Counters in this class are normally used for the assay of beta activity.
GEC Ltd.	GM4LB	2·54 × 5·4 ex. window flange	1·5	Ni-plated copper	(a) Al, 7 (b) 2·5 dia.	Anode wire	A/ethyl formate	1300	150	0·1	100	—	—	6×10^8	3×10^4	6*	—	
	GM4 (CV2138)	2·54 × 6·7 ex. window flange	2·6	Ni-plated copper	(a) Al, 7 (b) 2·5 dia.	Anode wire	A/ethyl formate	1350	200	0·1	100	−20/+50	0·25	6×10^8	3×10^4	10*	—	
	EHM2S (CV2139)		1·5	Ni-plated copper	(a) Mica 1·6–2·4 (b) 2·4 dia.	Anode wire	A/He/ethyl formate	1500	200	0·1	150	−20/+50	0·25	6×10^8	3×10^4	9*	—	
	2B2	5·0 × 7·6 ex. window flange	2·0	Ni-plated copper	(a) Mica 1·6–2·4 (b) 4·8 dia.	Anode wire	A/He/ethyl formate	1500	200	0·1	150	−20/+50	0·25	4×10^8	3×10^4	35*	—	
	2B7		3·2	Ni-plated copper	(a) Al, 7 (b) 4·8 dia.	Anode wire	A/ethyl formate	1500	200	0·1	220	−20/+50	0·25	4×10^8	3×10^4	36*	—	
	XA1	2·0 × 14·0 ex. window flange	10	Fe in soda-lime glass envelope	(a) Mica 7 (b) 1·8 dia.	Flexible leads	A/ethyl formate	1500	200	0·1	250	−20/+50	0·25	5×10^8	3×10^4	30*	—	Intended as detector of low energy X-radiation, especially Cu Kα.
Mullard Ltd.	MX113	1·27 × 8·6	2·0	Cr-Fe	(a) Mica 1·0–1·4 (b) 0·635 dia.	Anode top cap	Ne/A/Halogen	650	100	0·15	60	−55/+75	0·1	$>5 \times 10^{10}$	unlimited	2·5	350	May also be used as a mean current detector. Max recommended current 50μA.
	MX147	1·70 × 5·0	4·0	Cr-Fe	(a) Mica 2–3 (b) 0·9 dia.	Solder tags	Ne/A/Halogen	450	225	0·02	75	−55/+75	0·5	$>5 \times 10^{10}$	unlimited	20	—	
	MX108	3·0 × 11·2	3·8	Cr-Fe	(a) Mica 3·5–4·0 (b) 1·7 dia.	Special base	Ne/A/Halogen	400	100	0·15	130	−55/+75	0·2	$>5 \times 10^{10}$	unlimited	20	—	
	MX148	2·55 × 5·5	3·6	Cr-Fe	(a) Mica 1·5–2·0 (b) 1·98 dia.	Solder tags	Ne/A/Halogen	500	225	0·02	95	−55/+75	0·5	$>5 \times 10^{10}$	unlimited	25	—	
	MX152	2·6 × 3·2	1·3	Cr-Fe	(a) Mica 1·5–2·0 (b) 1·98 dia.	Solder tags	Ne/A/Halogen	550	200	0·03	150	−55/+75	—	$>5 \times 10^{10}$	unlimited	5	—	Background in 4 in. Pb. <1 counts/min when used with a/c tube MX154.
	MX123	3·5 × 6·8	2·6	Cr-Fe	(a) Mica 1·5–2·5 (b) 2·4 dia.	Anode turret	Ne/A/Halogen	650	150	0·15	50	−55/+75	0·1	$>5 \times 10^{10}$	unlimited	10	1900	
	MX149	3·35 × 5·5	3·6	Cr-Fe	(a) Mica 2·5–3·5 (b) 2·78 dia.	Solder tags	Ne/A/Halogen	500	250	0·02	180	−55/+75	0·5	$>5 \times 10^{10}$	unlimited	40	—	
	MX153	2·6 × 3·2	1·3	Cr-Fe	(a) Mica 10 (b) 2·78 dia.	Solder tags	Ne/A/Halogen	550	200	0·03	200	−55/+75	—	$>5 \times 10^{10}$	unlimited	8	—	Background in 4 in. Pb. <1·5 counts/min with a/c tube MX155.
	MX118	2·54 × 17	11	Cr-Fe	(a) Mica 3·5–4·0													

	MX118	2·54 × 17	11	Cr-Fe	(a) Mica 3·5–4·0 (b) 2·0 dia.	Anode top Cap	A/Halogen	1200	200	0·1	150	−55/+75	0·2	>5 × 10¹⁰	unlimited	50	—	These tubes are intended as detectors of low energy X-radiation, in the range 5–25 keV.
	MX122						Kr/Halogen	1000	200	0·1	370	+10/+40	5	>5 × 10¹⁰	unlimited	50	—	
20th Century Electronics Ltd.	Mb4H	2·5 × 10·5 ex. window flange	4·0	Cr-Fe in glass envelope	(a) Glass 10 (b) 0·5 dia.	Small octal base	Ne/A/Halogen	375	100	0·15	100	−55/+60	0·2	>10¹⁰	unlimited	10	—	
	EWG5H	3 × 12·5	5·0	Cr-Fe in glass envelope	(a) Glass 10–15 (b) 2·0 dia.	Belling Lee B2A	Ne/A/Halogen	375	100	0·15	100	−55/+60	0·2	>10¹⁰	unlimited	10	2450	Enclosed in Neoprene shock-proof jacket, with Ni-plated gauze protector over window.
	EW2C	2·5 × 5·3 ex. window flange	1·3	Ni-plated Cu	(a) Mica 1·5–3 (b) 2·4 dia.	Flexible leads	A/He/ethyl formate	1500	200	0·1	150	−20/+50	0·3	6 × 10⁸	3 × 10⁴	7	—	Background 1 count/min in a/c rig.
	EW2e	2·5 × 5·3 ex. window flange	1·3	Ni-plated Cu	(a) A1, 7 (b) 2·4 dia.	Flexible leads	A/ethyl formate	1350	200	0·1	150	−20/+50	0·3	6 × 10⁸	3 × 10⁴	9-12	—	
	EW2a	2·5 × 6·8 ex. window flange	1·5	Ni-plated Cu	(a) Mica 1·0–3·0 (b) 2·4 dia.	Flexible leads	A/He/ethyl formate	1500	200	0·1	150	−20/+50	0·3	6 × 10⁸	3 × 10⁴	9	—	
	EW2b (CV2138)	2·5 × 6·8 ex. window flange	1·5	Ni-plated Cu	(a) A1, 7 (b) 2·4 dia.	Tags	A/ethyl formate	1350	200	0·1	150	−20/+50	0·3	6 × 10⁸	3 × 10⁴	9	—	
	EW2g (CV2139)	2·5 × 6·8 ex. window flange	1·5	Ni-plated Cu	(a) Mica 1·6–2·4 (b) 2·4 dia.	Tags	A/He/ethyl formate	1500	200	0·1	150	−20/+50	0·3	6 × 10⁸	3 × 10⁴	9	—	
	EW3H	3·7 × 10·5	3·0	Cr-Fe foil in glass envelope	(a) Mica 1·5–2·5 (b) 2·5 dia.	Small octal base	Ne/A/Halogen	600	100	0·1	150	−55/+60	1·5	>10¹⁰	3 × 10⁴	15	—	
	EW5a	5·0 × 7·8 ex. window flange	3·0	Ni-plated Cu	(a) Mica 1·3 (b) 5·0 dia.	Anode end cap	A/He/ethyl formate	1300	200	0·1	220	−20/+50	0·3	5 × 10⁸	3 × 10⁴	38	—	
	EW5b	5·0 × 7·8 ex. window flange	3·0	Ni-plated Cu	(a) A1, 7 (b) 5·0 dia.	Anode end cap	A/ethyl formate	1300	200	0·1	220	−20/+50	0·3	5 × 10⁸	3 × 10⁴	38	—	
2. Thin tubular wall beta counters																		
Mullard Ltd.	MX133	1·8 × 14·5 (excluding base)	6·0	Cr-Fe wire spiral	(a) Glass 25–35 (b) 1·6–1·8 dia	Octal base	Ne/A/Halogen	425	100	0·15	90	−55/+75	0·1	>5 × 10¹⁰	unlimited	12	3200	These counters have a tubular thin wall section, and are intended for dipping into active liquids or for general measurement of surface beta activity. In the first six counters in this section the diameter increases at one end to 3·5 cm to accommodate a standard octal valve base.
20th Century Electronics Ltd.	B6 (CV2140) B6H	1·8 × 14·5 excluding base)	6·0	Carbon Cr-Fe spiral	(a) Glass 25–35 (b) 1·6–1·8 dia.	Octal base Octal base	A/ethyl formate Ne/A/Halogen	1100	200	0·1	100	−20/+50	2	10⁹	3 × 10⁴	13	2900	
								375	100	0·15	100	−55/+60	0·2	>10¹⁰	3 × 10⁴	15		
	B12 (CV494)	1·8 × 2·05 (excluding base	12·0	Carbon	(a) Glass 30–35 (b) 1·6–1·8 dia.	Octal base	A/ethyl formate	1100	200	0·1	100	−20/+50	2	10⁹	3 × 10⁴	26		
	B12H		12·0	Cr-Fe spiral		Octal base	Ne/A/Halogen	375	100	0·15	100	−55/+60	0·2	>10¹⁰	3 × 10⁴	30	5800	
	B24 (CV2143)	1·8 × 3 25 (excluding base)	24	Carbon	(a) Glass 35–40 (b) 1·6–1·8 dia.	Octal base	A/ethyl formate	1150	200	0·1	100	−20/+50	2	10⁹	3 × 10⁴	62		
	B7H	1·8 × 10·3	7	Cr-Fe spiral	(a) Glass 25–35	Flexible leads	Ne/A/Halogen	400	100	0·15	100	−55/+60	0·2	>10¹⁰	3 × 10⁴	18	3500	Uniform dia., no base.
	B15H	1·8 × 20·3	15	Cr-Fe spiral	(b) 1·6–1·8 dia.	Flexible leads	Ne/A/Halogen	375	100	0·15	100	−55/+60	0·2	>10¹⁰	3 × 10⁴	38	7000	
	B10Hb	2·1 × 14·5	10	Cr-Fe sheet with aperture	(a) Glass 45–50 (b) aperture 1 × 10	Flexible leads	Ne/A/Halogen	375	100	0·15	100	−55/+60	0·2	>10¹⁰	3 × 10⁴	37	3900	
3. Liquid sample beta counters																		
Mullard Ltd.	MX 142	2·3 × 10·5 (excluding base) 5 ml capacity	2·0	Cr-Fe spiral	(a) Glass 13·5–17 (b) 1·0 dia.	Belling Lee B2A base	Ne/A/Halogen	400	100	—	—	−55/+75	—	>5 × 10¹⁰	unlimited	5	—	The thin-wall section is surrounded by a glass 'skirt', so that a liquid sample may be contained in the annular space outside the cathode. In type DM6 the skirt terminates in a ground-glass joint and is detachable. In type MX 124 the sample volume is enclosed by a ground-glass stopper. Type M6 is available with or without a ground - glass stopper. Electrical connections are to two short rigid pins.
	MX124/01	2·5 × 18·5 9 ml capacity	6·0	Cr-Fe spiral	(a) Glass 25–35	Short pins	Ne/A/Halogen	425	100	0·15	90	−55/+75	0·1	>5 × 10¹⁰	unlimited	12	3200	
	MX124	3·2 × 23·5 9 ml capacity with stopper	6·0	Cr-Fe spiral	(a) Glass 25–35	Short pins	Ne/A/Halogen	425	100	0·15	90	−55/+75	0·1	>5 × 10¹⁰	unlimited	12	3200	
20th Century Electronics Ltd.	M2H (CV2886)	2·3 × 10·6 (excluding base) 5 ml capacity	2	Cr-Fe spiral	(a) Glass 13·5–17 (b) 1·0 dia.	Belling Lee B2A base	Ne/A/Halogen	375	100	0·15	100	−55/+60	0·2	>10¹⁰	3 × 10⁴	7	750	
	M6 (CV2145)	2·4 × 18·5 9 ml capacity	6	Carbon	(a) Glass 25–35	Short pins	A/ethyl alcohol	1100	200	0·1	100	+10/+60	5	10⁹	3 × 10⁴	12	—	
	M6H		6	Cr-Fe spiral	(a) Glass 25–35	Short pins	Ne/A/Halogen	375	100	0·15	100	−55/+60	0·2	>10¹⁰	3 × 10⁴	16	2900	
	DM6	2·4 × 19·5 9 ml capacity, demountable	6	Carbon	(a) Glass 25–35	Short pins	A/ethyl alcohol	1100	200	0·1	100	+10/+60	5	10⁹	3 × 10⁴	12	—	
	M12	2·4 × 25·0 17 ml capacity	12	Carbon	(a) Glass 25–35	Short pins	A/ethyl alcohol	1100	200	0·1	100	+10/+60	5	10⁹	3 × 10⁴	24	—	
4. Liquid flow counters																		
20th Century Electronics Ltd.	FM6	2·4 × 24	6	Carbon	Pyrex glass envelope	Short pins	A/ethyl alcohol	1100	200	0·1	100	+10/+60	5	10⁹	3 × 10⁴	12	—	Similar to M6 above, but with half capacity enclosed jacket with inlet and outlet tubes.
	F10	2·8 × 21·6	10	Carbon	Pyrex glass envelope	British 4-pin base	A/ethyl alcohol	1140	200	0·1	100	+10/+60	5	10⁹	3 × 10⁴	18	—	Internal glass tube helix 1 mm dia. liquid capacity 1 ml; inlet, outlet tubes.
	W10	2·0 × 23·0	10	Carbon	Pyrex glass envelope	Anode—long sleeved wire cathode—short side pin	A/ethyl alcohol	1150	200	0·1	100	+10/+60	5	10⁹	3 × 10⁴	20	—	Open-ended tube runs internally down active volume parallel to axis.
	FW10	2·0 × 23·0	10	Carbon	Pyrex glass envelope		A/ethyl alcohol	1150	200	0·1	100	+10/+60	5	10⁹	3 × 10⁴	20		

Geiger Counters — Continued

MANUFACTURER	MANUFACTURERS' TYPE NUMBER	OVERALL DIMENSIONS DIA. × LENGTH, cm	ANODE LENGTH, cm	CATHODE MATERIAL	(a) WINDOW/WALL MATERIAL AND THICKNESS, mg/cm² (b) WINDOW/WALL SIZE, cm	ELECTRICAL CONNECTIONS	GAS FILLING	WORKING VOLTAGE Vw, V	PLATEAU LENGTH, MIN, V	PLATEAU SLOPE MAX, %/V	DEAD TIME AT Vw, μs	TEMP. RANGE, °C	AVERAGE TEMP. COEFF. of Vw V/°C	AVERAGE LIFE, counts	MAX. RECOMMENDED COUNT-RATE, counts/min	BACKGROUND IN 2 in. Pb counts/min	GAMMA SENSITIVITY counts/min mr/h Eγ ≃ 1 Mev	REMARKS
5. 'Needle' counters																		
20th Century Electronics Ltd.	N1B	2·5 × 26·8 Needle 0·3 × 15	1·2	ss	(a) ss 80 mg/cm² (b) 0·3 dia.	Anode flexible lead, cathode flange	A/ethyl formate	750	70	0·1	150–250	—	1	10^8		4	—	Miniature beta / gamma counters, intended for medical and diagnostic applications. May be completely sterilized. The active volume is at the end of the ss needle.
	N1C	2·8 × 21·8 Needle 0·3 × 10	1·2	ss	(a) ss 80 mg/cm² (b) 0·3 dia.	Anode flexible lead, cathode flange	A/ethyl formate	750	70	0·1	150–250	—	1	10^8		4	—	
	N1K	2·8 × 21·8 Needle 0·2 × 10	1·2	ss	(a) ss 40 mg/cm² (b) 0·2 dia.	Anode flexible lead, cathode flange	A/ethyl formate	750	70	0·1	150–200	—	1	10^8		4	—	
6. Gamma counters																		
GEC Ltd.	5GH (CV2247)	3·0 × 12·5	5	Cr-Fe	Glass envelope enclosed in Neoprene shock-proof jacket	Belling Lee B2A 2-pin base	Ne/A/Halogen	385	90	0·15	120	−55/+50	0·2	$>10^9$	unlimited	—	—	
	12GH (CV2287)	2·9 × 19·5	12	Cr-Fe	Glass envelope	Solder tags	Ne/A/Halogen	380	90	0·15	120	−55/+40	0·2	$>10^9$	unlimited	35	—	
	G150	3·8 × 150	135	External carbon cathode	Soda-lime glass envelope	Octal base	A/ethyl formate	1300	200	0·1	400	−0/+50	—	2×10^8	3×10^4	1200	—	Unshielded background.
Mullard Ltd.	MX146	1·7 × 5·0	4·0	Cr-Fe	Cr-Fe 250 mg/cm²	Solder tags	Ne/A/Halogen	450	225	0·02	75	−55/+75	0·5	75×10^{10}	unlimited	20	—	
	MX120/01	2·25 × 17	14	Cr-Fe	Cr-Fe	Flexible leads	Ne/A/Halogen	400	100	0·15	190	−55/+75	0·1	$>5 \times 10^{10}$	unlimited	40	6800	Efficiency of MX141 for the detection of I-131 gamma is 2·9 times higher than MX120/01.
	MX141	2·25 × 17	14	W	—	Flexible leads	Ne/A/Halogen	400	100	0·15	190	−55/+75	0·1	$>5 \times 10^{10}$	unlimited	40	9000	
	MX156	2·25 × 25	22	Cr-Fe	Cr-Fe	Flexible leads	Ne/A/Halogen	400	100	0·10	190	−55/+75	0·1	$>5 \times 10^{10}$	unlimited	70	$1{\cdot}2 \times 10^4$	
	MX145	2·25 × 27	24	Cr-Fe	Cr-Fe	Flexible leads	Ne/A/Halogen	400	100	0·1	190	−55/+75	0·1	$>5 \times 10^{10}$	unlimited	75	$1{\cdot}3 \times 10^4$	
	MX115 (CV2246)	3·0 × 11·2	4·5	Cr-Fe	Cr-Fe 375 mgm/cm²	Belling Lee B2A base	Ne/A/Halogen	400	100	0·15	170	−55/+75	0·2	$>5 \times 10^{10}$	unlimited	20	2250	Enclosed in Neoprene shock-proof jacket.
	MX154	8·0 × 9·0	—	Cr-Fe	Cr-Fe 750 mgm/cm²	Tags	Ne/A/Halogen	1000	400	0·04	1000	−55/+75	—	$>5 \times 10^{10}$	unlimited	80	—	a/c guard tube for MX152, background in 4 in. Pb.
	MX155	8·0 × 9·0	—	Cr-Fe	Cr-Fe 750 mgm/cm²	Tags	Ne/A/Halogen	1000	400	0·04	1000	−55/+75	—	$>5 \times 10^{10}$	unlimited	80	—	a/c guard tube for MX153, background in 4 in. Pb.
20th Century Electronics Ltd.	G4Pb	1·7 × 10 (inc. base)	4	Lead	Pyrex glass envelope	4-pin HIVAC base	A/ethyl formate	1100	200	0·1	100	−20/+50	1	10^9	3×10^4	15	—	
	G4H	1·7 × 10 (inc. base)	4	Cr-Fe	Pyrex glass envelope	4-pin HIVAC base	Ne/A/Halogen	370	100	0·15	100	−55/+60	0·2	$>10^{10}$	3×10^4	10	950	
	MG10H	1·4 × 14·8	10	Cr-Fe	Pyrex glass envelope	Flexible leads	Ne/A/Halogen	380	100	0·15	100	−55/+60	0·2	$>10^{10}$	3×10^4	30	3250	
	G5H	3·0 × 12·5 (inc. base)	5	Cr-Fe	Pyrex glass envelope	Belling Lee B2A base	Ne/A/Halogen	375	100	0·15	120	−55/+60	0·2	$>10^{10}$	3×10^4	20	2450	
	G12	2·3 × 15	12	Copper	Pyrex glass envelope	End caps	A/ethyl formate	1300	200	0·1	100	−20/+50	1	10^9	3×10^4	33	—	
	G24 (CV411)	2·3 × 27·5	24	Copper	Pyrex glass envelope	End caps	A/ethyl formate	1300	200	0·1	100	−20/+50	1	10^9	3×10^4	65	—	
	G24H (CV2147)	2·3 × 26·0	24	Cr-Fe	Pyrex glass envelope	End caps	Ne/A/Halogen	375	100	0·15	100	−55/+60	0·2	$>10^{10}$	3×10^4	65	9500	
	G10H	2·6 × 20·0 (inc. base)	10	Cr-Fe	Pyrex glass envelope	B5 4-pin base	Ne/A/Halogen	380	100	0·15	150	−55/+60	0·2	$>10^{10}$	3×10^4	40	6200	
	G10Pb	2·6 × 20·0 (inc. base)	10	Lead	Pyrex glass envelope	B5 4-pin base	A/ethyl formate	1100	200	0·1	100	−20/+60	1	10^9	3×10^4	60	—	
	G10	2·6 × 20·0 (inc. base)	10	Carbon	Pyrex glass envelope	B5 4-pin base	A/ethyl formate	1100	200	0·1	100	−20/+60	2	10^9	3×10^4	40	—	
	G10He (CV2287)	2·9 × 20·0 (inc. base)	12	Cr-Fe	Pyrex glass envelope	Solder tags	Ne/A/Halogen	380	100	0·15	150	−55/+60	0·2	$>10^{10}$	3×10^4	40	6200	
	G26	3·8 × 35·5 (inc. base)	26	Carbon	Pyrex glass envelope	B5 4-pin base	A/ethyl formate	1100	200	0·1	100	−20/+50	2	10^9	3×10^4	100	—	
	G26Pb	3·8 × 35·5 (inc. base)	26	Lead	Pyrex glass envelope	B5 4-pin base	A/ethyl formate	1300	200	0·1	100	−20/+50	1	10^9	3×10^4	150	—	
	G38	3·8 × 50·0	38	Carbon	Pyrex glass envelope	End caps	A/ethyl formate	1300	200	0·1	100	−20/+50	2	10^9	3×10^4	235	—	
	G47	3·8 × 60·0	47	Carbon	Pyrex glass envelope	End caps	A/ethyl formate	1190	200	0·1	100	−20/+50	2	10^9	3×10^4	265	—	
	G60 (CV2149)	3·8 × 75·0	60	Carbon	Pyrex glass envelope	End caps	A/ethyl formate	1200	200	0·1	100	−20/+50	2	10^9	3×10^4	300	—	
	G60Pb	3·8 × 75·0	60	Lead	Pyrex glass envelope	End caps	A/ethyl formate	1300	200	0·1	100	−20/+50	2	10^9	3×10^4	400	—	
	G60H	3·8 × 75·0	60	Cr-Fe	Pyrex glass envelope	End caps	Ne/A/Halogen	375	100	0·15	100	−55/+60	0·2	$>10^{10}$	3×10^4	300	$4{\cdot}9 \times 10^4$	
	G53	3·8 × 64·8	53	Brass	Brass	Solder tags	A/ethyl formate	1740	200	0·1	100	−20/+50	1	10^9	3×10^4	250	—	
	G84	3·8 × 95·2	84	Brass	Brass	Solder tags	A/ethyl formate	1740	200	0·1	100	−20/+50	1	10^9	3×10^4	400	—	
7. Mean current counters																		

	G60H	3·8×75·0	60	Cr-Fe	Pyrex glass envelope	End caps	Ne/A/Halogen	375	100	0·4	100	−55/+40	0·2						
	G53	3·8×64·8	53	Brass	Brass	Solder tags	A/ethyl formate	1740	200	0·1	100	−20/+50	1	10^9	2×10^3	250			
	G84	3·8×95·2	84	Brass	Brass	Solder tags	A/ethyl formate	1740	200	0·1	100	−20/+50	1	10^9	3×10^3	400			
7. Mean current counters																			
GEC Ltd.	3GHH	1·0×6·5	3	Cr-Fe	Glass envelope	Flexible leads	Ne/A/Halogen	340	60	0·4	—	−55/+40	—	—	—	—	—	Small gamma or beta/gamma / counters which may be used as pulse counters or as mean current detectors at higher radiation intensities.	
Mullard Ltd.	MX150	0·7×3·8	1·6	Cr-Fe	Cr-Fe 80–100	Anode pin	Ne/A/Halogen	475	100	0·15	50	−40/+75	0·5	$>5\times10^{10}$	unlimited	2	—		
	MX119	1·0×8·0	4	Cr-Fe	Cr-Fe 80–100	Flexible leads	Ne/A/Halogen	400	200	0·15	35	−40/+75	—	—	—	1·5	570		
	MX128	1·0×8·0	—	Cr-Fe	Cr-Fe 80–100	Flexible leads	Ne/A/Halogen	400	50	—	—	−40/+75	—	—	—	—	—		
20th Century Electronics Ltd.	BHC1	0·8×4·4	—	Cr-Fe	Cr-Fe 80–100	Anode pin	Ne/Halogen	400	80	—	15	−30/+60	0·2	$>10^{10}$	—	10	—		
	HC2	1·25×5·8	—	Cr-Fe	Cr-Fe 80–100	Flexible leads	Ne/A/Halogen	425	100	0·15	30	−50/+60	0·2	$>10^{10}$	—	4	—		
	HC4	1·25×8·4	4	Cr-Fe	Cr-Fe 80–100	Flexible leads	Ne/A/Halogen	—	—	—	—	−50/+60	0·2	$>10^{10}$	—	7	600		
8. Windowless flow counters																			
20th Century Electronics Ltd.	WF1	4·5×29	—	Cr-Fe	Glass envelope	End caps	'p' gas, supplied in h.p. cylinders by manufacturer	1200	200	0·05(av)	—	—	—	—	—	20	—	Single position windowless flow counter.	
	WF2	17×19·7	—	Ni-plated brass	Ni-plated brass	PET 237 plug		1300	200	0·05(av)	—	—	—	—	—	28	—	3-position windowless flow counter including a position for pre-flushing before counting.	

TABLE 2 Proportional Counters

			CONSTRUCTION					OPERATION					
TYPE	MANUFACTURER	MANUFACTURERS TYPE NO.	OVERALL DIMENSIONS, DIA. × LENGTH, cm	ANODE LENGTH, cm	(a) CATHODE MATERIAL AND THICKNESS (b) WINDOW MATERIAL, SIZE, THICKNESS	ELECTRICAL CONNECTIONS	GAS, AND ABSOLUTE FILLING PRESSURE	THERMAL NEUTRON SENSITIVITY, counts per neutron/cm²	OPERATING POTENTIAL, Vw	GAS GAIN AT Vw	CHARGE/PULSE AT OPERATING POINT, COULOMBS	MAX. OPERATING TEMP., °C.	REMARKS
1. BF_3-filled neutron-sensitive proportional counters	20th Century Electronics Limited	5EB40/13	1·3×11·5	5	(a) 0_2-free Cu, 0·015 in. (b) n.a.	All BF_3 counters are available (i) unterminated, when a metal/glass seal is exposed, (ii) with PET 237 plug (iii) with Amphenol HN series plug. Suffix 'G' on type number indicates a guard-ring anode connection.	enriched BF_3, 40 cm Hg	0·32	1200	30	$1·9\times10^{-14}$	100	All BF_3 counters are also available with a natural concentration of B—10, when the suffix 'E' is omitted from the type number. The neutron sensitivity is reduced by a factor 5.
		28EB40/13	1·3×34	28	(a) 0_2-free Cu, 0·015 in. (b) n.a.		enriched BF_3, 40 cm Hg	1·75	1200	30	$1·9\times10^{-14}$	100	
		12EB20	2·5×21	12	(a) 0_2-free Cu, 0·02 in. (b) n.a.		enriched BF_3, 20 cm Hg	1·5	1200	30	$1·9\times10^{-14}$	100	
		12EB40	2·5×21	12			enriched BF_3, 40 cm Hg	3·0	1750	30	$1·9\times10^{-14}$	100	
		12EB70G	2·5×22	12			enriched BF_3, 70 cm Hg	5·2	2350	30	$1·9\times10^{-14}$	100	
		31EB20	2·5×41	31	(a) 0_2-free Cu, 0·02 in. (b) n.a.		enriched BF_3, 20 cm Hg	3·8	1200	30	$1·9\times10^{-14}$	100	All these counters are based on AERE designs.
		31EB40	2·5×41	31			enriched BF_3, 40 cm Hg	7·6	1750	30	$1·9\times10^{-14}$	100	
		31EB70G	2·5×42	31			enriched BF_3, 70 cm Hg	13·5	2350	30	$1·9\times10^{-14}$	100	
		15EB70/50G	5·0×28	15	(a) 0_2-free Cu, 0·025 in. (b) n.a.		enriched BF_3, 70 cm Hg	27·5	3400	30	$1·9\times10^{-14}$	100	
		40EB70/50G	5·0×54	40			enriched BF_3, 70 cm Hg	73·0	3400	30	$1·9\times10^{-14}$	100	
		84EB45/50G	5·0×100	84			enriched BF_3, 45 cm Hg	83·5	2350	30	$1·9\times10^{-14}$	100	
		107EB70/50G	5·0×119	107			enriched BF_3, 70 cm Hg	196	3400	30	$1·9\times10^{-14}$	100	
2. Sealed-off X-ray proportional counters	Mullard Ltd.	MX132	2·5×11		(a) Cr-Fe (b) Side window mica, 14×4 mm, 1·5–2 mg/cm²		Xe/CH_4	n.a.	1500	10^3			
	20th Century Electronics Limited	PX28E	1·9×9·7		(a) A1, 0·036 in.	Flexible anode connection	A/CH_4, 70 cm Hg	n.a.	1650	12·5		50	Energy resolution <15% for 8 keV photons.
		PX28E/Xe			(b) Beryllium entry window 10×3 mm, 0·5 mm thick. Mica exit window, 10×3 mm, 3 mg/cm²		Xe/CH_4, 70 cm Hg	n.a.	1800	12·5		50	
		PX28F	1·9×9·7		(a) A1, 0·036 in.	Flexible anode connection	A/CH_4, 70 cm Hg	n.a.	1650	12·5		50	
		PX28F/Xe			(b) Be window 10×3 mm 0·5 mm thick		Xe/CH_4, 70 cm Hg	n.a.	1800	12·5		50	
		PX28L/Xe	2·2×11·0		(a) A1, 0·036 in. (b) Be window 28×3 mm 0·12 mm thick	Flexible anode connection	Xe/CH_4, 70 cm Hg	n.a.	1650	—		50	
		PX115	6·35×40	22·5	(a) A1, 0·03 in. over 11 cm length (b) n.a.	PET 237 plug	Xe/CH_4, 150 cm Hg	n.a.	4000	60		50	Energy resolution 6% for 59·6 keV photons.
		PX130/A	5·0×23		(a) A1, 0.187 in. (b) Be window 22 mm dia, 0·5 mm thick with 1 mm wide Al support strut	PET 237 plug	A/CH_4, 70 cm Hg	n.a.	1800	60		50	Energy resolution 17% for 50 keV photons.
		PX130/Xe					Xe/CH_4, 70 cm Hg	n.a.	2000	60		50	
3. Fast neutron proportional counters	General Radiological Limited	FN2/2	5·0×13·3		Cathode is a series of aluminized polythene cylinders and disks which act as radiators for proton recoils. Envelope is ss 0·036 in.	Anode wire from glass/metal seal. Cathode solder tag.	A/CH_4	0·46 counts/s	1400	10^3	$8·8\pm4·0\times10^{-13}$	30	The count rate under 'neutron sensitivity' is that corresponding to 1 mpl fast neutrons in the energy range 0·15–14 MeV.
		FN2/3	5·0×16·5				A/CH_4	0·7 counts/s	1400			30	
		FN2/6	5·0×27·3				A/CH_4	1·4 counts/s	1400			30	
		FN2/12	5·0×49·5				A/CH_4	2·8 counts/s	1400			30	
	20th Century Electronics Limited	FN2/2	5·0×13·3		Envelope is ss 0·036 in. or copper 0·02 in.	"	A/CH_4	0·46 counts/s	1400		$8·8\pm4·0\times10^{-13}$	30	All these counters are based on Harwell designs.
		FN2/3	5·0×16·5				A/CH_4	0·7 counts/s	1400			30	
		FN2/6	5·0×27·3				A/CH_4	1·4 counts/s	1400			30	
		FN2/12	5·0×49·5				A/CH_4	2·8 counts/s	1400			30	

A range of proportional counters manufactured by Laboratorium Prof. Dr. Berthold, Western Germany, may be obtained from General Radiological Ltd. Full details not available.

TABLE 3 Mean current ionization chambers

TYPE	MANUFACTURER	MANUFACTURERS TYPE NO.	OVERALL DIMENSIONS DIA. × LENGTH in.	(a) WALL MATERIAL & THICKNESS, in. (b) ELECTRODE MATERIAL AND THICKNESS, in.	ELECTRODE SPACING mm	ELECTRICAL CONNECTIONS	COATING MATERIAL (3)	GAS, & ABS FILLING PRESSURE	THERMAL NEUTRON SENSITIVITY, ets/n cm²	GAMMA SENSITIVITY, A/r h	WORKING VOLTAGE, Vw	CURRENT RANGE, A	TEMPERATURE, °C	REMARKS
1. Neutron-sensitive chambers	General Radiological Ltd.	NEO65A(1)	3·5 × 13·5	(a) 99% Al, 0·064 (b) 99·8% Al, 0·064	col-outer 4 inner-col 5	Polythene-insulated cables permanently attached	enriched boron, 180mg	H_2 225 cm Hg 75 cm Hg 22·5 „	$2·2 \times 10^{-14}$ $1·4 \times 10^{-14}$ $5·4 \times 10^{-15}$	$4·5 \times 10^{-12}$ $1·5 \times 10^{-12}$ $4·5 \times 10^{-13}$	400	5×10^{-4} max.	80	Reactor control, gamma compensated, max. temp. 200°C without connectors.
		NEO66A(2)	3·5 × 13·5	(a) 99% Al, 0·064 (b) 99·8% Al 0·064	4	Polythene-insulated cables permanently attached	enriched boron, 256mg	H_2 225 cm Hg 75 cm Hg 22·5 „	$3·1 \times 10^{-14}$ $2·0 \times 10^{-14}$ $7·6 \times 10^{-15}$	$6·8 \times 10^{-12}$ $2·3 \times 10^{-12}$ $6·8 \times 10^{-13}$	600	6×10^{-4} max.	80	Reactor control, uncompensated, 200°C without connectors. (Both these chambers are available with completely detachable plug and socket connections, PET 237 or Amphenol series HN.)
	Plessey Nucleonics Ltd.	PNI1089	2·5 × 13·5	(a) 99% Al (b) 99·8% Al	4·1	HT: BICC type MPC 3146 4-core col: TCM type PT11GP single-core Perm. cable connections	enriched boron	H_2 225 cm Hg	2×10^{-14}	6×10^{-13}	400–600	10^{-4}	80	Reactor control, uncompensated.
		PNI1079	3·0 × 14·4	(a) 99% Al 0·064 (b) 99·9% Al 0·028	4·4	as for PNI1089	U-235, 400 mg, 400 cm³	A + 2%N_2, 2 ats	7×10^{-14}	3×10^{-11}	1000	10^{-2}	80	Reactor control, uncompensated.
		PNI1078	3·0 × 19·5	(a) 99% Al 0·064 (b) 99·9%Al 0·028	col-outer 3·9 inner-col 4·9	BICC MPC 5132/A 6-core, and PT11GP; fixed cables	enriched boron, 1000 cm³	H_2	4×10^{-14}	$1·3 \times 10^{-11}$	400–600	10^{-4}	80	Shockproof, low residual activity, gamma compensated chamber.
		PNI1025/1(1)	3·5 × 13·5	(a) 99% Al 0·064 (b) 99·8% Al 0·064	col-outer 4·0 inner-col 5·0	As for PNI1089 4-core cable to each HT electrode	enriched boron	H_2 225 cm Hg 75 cm Hg 25 cm Hg	$1·8 \times 10^{-14}$ $1·2 \times 10^{-14}$ $4·0 \times 10^{-15}$	$4·5 \times 10^{-12}$ $1·5 \times 10^{-12}$ $5·0 \times 10^{-13}$	400–600	1×10^{-4}	80	Reactor control, gamma compensated chamber. May be used up to 200°C if fitted with rigid extension leads by manufacturer.
		PNI1026/1(2)	3·5 × 13·5	(a) 99% Al 0·064 (b) 99·8% Al 0·064	4	As for PNI1809	enriched boron	H_2 225 cm Hg 75 cm Hg 25 cm Hg	$2·6 \times 10^{-14}$ $1·7 \times 10^{-14}$ $5·7 \times 10^{-15}$	$6·5 \times 10^{-12}$ $2·2 \times 10^{-12}$ $7·3 \times 10^{-13}$	400–600	1×10^{-4}	80	Reactor control, uncompensated. May be used up to 200°C if fitted with rigid extension leads by the manufacturer.
		PNI1025/2 and 1026/2				Detachable plug and socket connection type PET222							80	Identical to PNI1025/1, PNI1026/1 except for electrical connections.
		PNI1026/3		ss outer case		UR72 PTFE insulated cables							200	Identical with PNI1026/1 except for outer case, electrical connections, and working temperature. Intended for commissioning experiments in pressurized reactors.
	20th Century Electronics Ltd.	RC6EB(1)	3·5 × 13·5	(a) 99% Al, 0·064 (b) 99·9% Al 0·064	col-outer 3·7 inner-col 5	HT: 2 × TCM type BA24PSP twin-core col: TCM type PT11GP (mod) perm. cable conn.	enriched boron	H_2 225 cm Hg 75 cm Hg 25 cm Hg	$2·2 \times 10^{-14}$ $1·4 \times 10^{-14}$ 6×10^{-15}	$4·5 \times 10^{-12}$ $1·5 \times 10^{-12}$ 5×10^{-13}	400–600	3×10^{-4}	80	Reactor control, gamma compensated chamber. up to 200°C if fitted with rigid extension leads by the manufacturer.
		RC7EB(2)	3·5 × 13·5	(a) 99% Al, 0·064 (b) 99·9% Al, 0·064	4	As for RC6EB but only 1 × 2-core cables.	enriched boron	H_2 225 cm Hg 75 cm Hg 25 cm Hg	$3·0 \times 10^{-14}$ $1·9 \times 10^{-14}$ $8·0 \times 10^{-15}$	$6·8 \times 10^{-12}$ $2·3 \times 10^{-12}$ $7·6 \times 10^{-13}$	400–600	3×10^{-4}	80	Reactor control, uncompensated. May be used up to 200°C if fitted with rigid extension leads by manufacturer. (These chambers are available with complete detachable plug and socket connections PET 237 or Amphenol HN.)
	VIA Ltd.	RC1	3·5 × 12 ⅛, inc. terminals	(a) 99·8% Al, 0·064 (b) 99·8% Al, 0·02	6·2	Two insulated terminals with adaptors for attaching polythene—insulated cables; the terminals are pressure/vacuum tight with quartz-Pb comp. seals	enriched boron 500 cm³ enriched boron 200 cm³	H_2 150 cm Hg 15 cm Hg H_2 150 cm Hg 15 cm Hg	$2·4 \times 10^{-14}$ 6×10^{-15} $9·6 \times 10^{-15}$ $2·4 \times 10^{-15}$	6×10^{-12} 6×10^{-13} $3·3 \times 10^{-12}$ $3·3 \times 10^{-13}$	400–600	10^{-4}	50	Reactor control uncompensa ed. Temperature limit applies to chambers without connectors. Based on AERE types RC1, RC2.
		RC2	3·5 × 9 ⅜, inc. terminals	(a) 99·8% Al, 0·064 (b) 99·8% Al, 0·02	6·2									
2. Beta/gamma sensitive chambers	Elliott Bros. Ltd.	1590A	6·5 × 14	(a) brass (b) brass	4·75	col: Plessey Mk. IV concentric plugs HT: 4 BA stud	uncoated	open to air	n.a.	$1·8 \times 10^{-14}$	100	—	30	A flow chamber for measuring the beta activity in air, 2 × ⅛ in. copper pipes are provided for coupling to a flow system. The quoted current is produced by an activity in air of 10^{-12} c/cm³ of tritium.
	General Radiological Ltd.	NE006	3·67 × 7·0	(a) 99·8% Al, 950 mg/cm² (b) conducting phenolic resin, 450 mg/cm²	330 cm³ vol	Two glass/metal seals	uncoated	dry air 6·5 ats	n.a.	$1·97 \times 10^{-10}$	250	—	50	Gamma response independent of energy in range 60 keV—3 MeV. Other gas fillings and terminations to order. Based on AERE type 1390A.
		NE014	9·0 × 10·0	(a) Al, 0·16 cm, plastic covered. (b) beta window 0·68 mg/cm², 4·2 cm dia., cavity 6·7 cm i.d. × 12·7 cm deep	—	col: cable permanently attached HT: terminal	uncoated	air, open to at.	n.a.	Co–60, $5·3 \times 10^{-11}$ A/mc in 5 ml ampoule P-32, $2·7 \times 10^{-10}$ A/mc ml	300	5×10^{-9} for 99·7% saturation	50	Reference re-entrant thimble for standardization of solid or liquid beta, gamma sources. Beta sources are inserted in a flat tray at bottom of the chamber. Designed in conjunction with NPL and AERE (type 1383A).
		NE052	6·75 × 17	(a) mild steel 1·7 mm (b) Al, 1¼ dia. annular hole down axis	—	2 × Plessey Mk IV concentric plugs	uncoated	A, 5 ats	n.a.	(6×10^{-10})	100	10^{-8}	50	Wire activation chamber. Quoted current with tungsten wire activated to 0·7 e/s/cm. (For recommended wire this needs 1 h radiation in neutron flux of 10^{12} nv.) Based on AERE type 1544A.
	VIA Ltd.	TPA Mk I	7·28 × 19	(a) Mild steel, 0·1 (b) Al	4700 cm³ vol	2 screw terminals for cable attach-	uncoated	A, 20 ats H, 20 ats	— 7×10^{-15}	$1·28 \times 10^{-8}$ $1·15 \times 10^{-9}$	2000		50	Both based on AERE type TPA.

	NE052	6·75 × 17	(a) mild steel 1·7 mm (b) Al, 1¼ dia. annular hole down axis	—	2 × Plessey Mk IV concentric plugs	uncoated	A, 5 ats	n.a.	(6×10^{-10})	100	10^{-8}	50	Wire activation chamber. Quoted current with tungsten wire activated to 0·7 mA/m. (For recommended wire this needs 1 h radiation in neutron flux of 10^{12} nv.) Based on AERE type 1544A.
via Ltd.	TPA Mk I	7·28 × 19	(a) Mild steel, 0·1 (b) Al	4700 cm³ vol	2 screw terminals for cable attachment or Plessey Mk IV concentric plugs	uncoated	A, 20 ats H_2, 20 ats	— 7×10^{-14} (fast neutrons)	$1{\cdot}28 \times 10^{-8}$ $1{\cdot}15 \times 10^{-9}$	2000 —		50 50	Both based on AERE type TPA.
	TPA Mk II	7·28 × 19	(a) mild steel, 0·1 (b) Al	4700 cm³ vol	2 × Plessey Mk IV concentric plugs	uncoated	A, 20 ats	—	$1{\cdot}9 \times 10^{-9}$	160		50	Similar to TPA Mk I but with re-entrant thimble 1 in. or 2 in. in dia. and 13 in. deep for insertion of samples. Quoted gamma sensitivity and op. voet, is for 1 mc of Ra in 1 in. dia. thimble.

(*1*) Based on AERE chamber type RC6 (*2*) Based on AERE chamber type RC7 (*3*) All coatings of enriched boron may be replaced by natural boron, when the neutron sensitivity will normally be reduced by × 4.

TABLE 4 Pulse ionization chambers

TYPE	MANUFACTURER	MANUFACTURERS' TYPE NO.	OVERALL DIMENSIONS, DIA. × LENGTH, in.	(a) WALL MATERIAL AND THICKNESS, in. (b) ELECTRODE MATERIAL AND THICKNESS, in.	ELECTRODE SPACING, mm	ELECTRICAL CONNECTIONS	GAS & ABSOLUTE FILLING PRESSURE	WEIGHT OF FISSILE(*1*) COATING, mg	COATED AREA, cm² × COATED LENGTH, cm	NEUTRON SENSITIVITY, counts per neutron/cm²	OPERATING POTENTIAL, Vw	CHARGE/PULSE AT THE OPERATING POINT	MAXIMUM OPERATING TEMP, °C	REMARKS
1. Fission ionization chamber permanently attached to flexible polythene-insulated connector.	Plessey Nucleonics Ltd.	PNI1057	0·3 × 3·25	(a) Nilo K, 0·014 (b) ss 0·011	1·7	UR70 cable	A + 2% N_2 5 ats	2·5	2·5 × 1·9	2×10^{-3}	400	5×10^{-14}	80	Max. length of cable 12 ft.
		PNI1088	0·6 × 5·5	(a) ss 0·02 (b) ss 0·094	2	UR70 cable	A + 2% N_2 5 ats	25	25 × 6·5	$2{\cdot}5 \times 10^{-2}$	500	5×10^{-14}	80	Max. length of cable 12 ft.
		PNI1079	3 × 14·4	(a) 99% Al, 0·064 (b) 99·99% Al, 0·064	4·4	HT: BICC type MPC3416 (4 core) col: TCM 2ats type PT11GP (single)	A + 2% N_2	400	400 × 22·5	0·4	1000	5×10^{-14}	80	Also used as mean current chamber. See table 3. Max. length of cable 12 ft.
	20th Century Electronics Ltd.	FC05/1000(*4*)	0·25 × 2·75	(a) Nilo K, 0·01 (b) ss 0·005	0·92	TCM type PT77M cable	A + 2% N_2 5½ ats	0·55(*2*)	0·55 × 0·5	$3{\cdot}7 \times 10^{-4}$	250	7×10^{-14}	80	Overall diameter includes a detachable cadmium sleeve 0·5 mm thick. Max. length of cable 15 ft.
		FC4/10 (*4*) FC4/1000(*4*)	0·25 × 2·75	(a) Nilo K, 0·01 (b) ss 0·005	1·5	PT77M cable	A + 2% N_2 5½ ats	0·04(*3*) 4·0(*3*)	3·8 × 1·0	3×10^{-5} 3×10^{-3}	250	7×10^{-14}	80	Max. length of cable 15 ft.
2. Chamber sealed off, the electrical connection being a plug on the chamber or at the remote end of the rigid extension lead welded to the chamber. The extension lead commonly has a diameter of about 0·625 in.	Plessey Nucleonics Ltd.	PNI1070	1·5 × 12·6	(a) ss 0·022 (b) ss 0·022	1·9	PET222 plug	A + 2% N_2 5 ats	150	150 × 18	0·15	1000	5×10^{-14}	80	300°C when fitted with rigid extension lead by manufacturers. Max. length 15 ft.
		PNI1049	2·0 × 13·75	(a) ss 0·02 (b) ss 0·02	2	PET222 plug	A + 2% N_2 5 ats	200	200 × 18	0·2	1000	5×10^{-14}	80	300°C when fitted with rigid extension lead by manufacturers. Max. length 15 ft.
	20th Century Electronics Ltd.	FC15/1000(*4*) FC35/1000(*4*)	0·875 × 6·71	(a) ss 0·025 (b) ss 0·02	1·2	PET237 plug	A + 2% N_2 5½ ats	14·5(*2*) 34(*2*)	14·5 × 2·4 34 × 2·4	$1{\cdot}05 \times 10^{-2}$ $2{\cdot}4 \times 10^{-2}$	500		80	200°C when fitted with ¼ in. dia. rigid extension lead by manufacturers. Max. length 15 ft.
		FC165/1000(*4*)	1·18 × 8·09	(a) ss 0·025 (b) ss 0·02	1·2	PET237 plug	A + 2% N_2 5½ ats	165(*2*)	165 × 5·75	0·12	500		80	200°C when fitted with ¼ in. dia. rigid extension lead by manufacturers. Max. length 15 ft.
3. Chamber supplied permanently attached to a rigid metal extension.	Plessey Nucleonics Ltd.	PNI1109	0·063 × 36 inc. extension	(a) ss 0·005 (b) ss 0·003	0·48	PET222 plug on a 1·25 in. × 6 in. long extension	A + 2% N_2 20 ats	0·5	0·5 × 1·9	4×10^{-4}	500	5×10^{-14}	80	Rigid extension lead 0·063 in. dia. ss, unconfined gas volume.
	20th Century Electronics Ltd.	LTFC3/1000(*4*)	0·25 × 36 max. inc. extension	(a) Ni, 0·02 (b) Ni, 0·0065	1·5	PET237 plug	A + 2% N_2 5½ ats	3·1(*2*)	3·1 × 2·0	$2{\cdot}2 \times 10^{-3}$	500		80	Rigid extension ¼ in. dia., Ni, unconfined gas volume. Any length up to 36 in.
		FCO8/1000(*4*)	0·125 × 48 inc. extension	(a) Nimonic 75, 0·01 (b) ss 0·0045	0·75	PET142 plug	99·99% A 125 lb/in²a	0·75(*3*)	0·75 × 1·0	6×10^{-4}	200	8×10^{-14}	600	Rigid extension lead 0·125 in. dia. × 48 in. long Nimonic 75 unconfined gas volume.
		HTFC3/1000(*4*)	0·25 × 15 ft max. inc. extension	(a) Nimonic 75, 0·02 (b) Platinum, 0·006	1·9	Ni wire, unterminated	Xe 4½ ats	3·1(*3*)	3·1 × 2	$2{\cdot}2 \times 10^{-3}$	50		850	Rigid extension lead ¼ in. dia. Nimonic 75 unconfined gas volume.
		HTFC4/1000(*4*)	0·25 × 60 inc. extension	(a) ss 0·018 (b) ss 0·01	1·7	PET237 plug	99·99% A 3 ats	3·9(*2*)	3·9 × 2·5	3×10^{-3}	250	7×10^{-14}	500	Rigid extension lead ¼ in. dia. ss unconfined gas volume.
		HTFC10/1000(*4*)	0·5 × 4·94	(a) ss 0·02 (b) ss 0·008	2·8	PET237 plug	99·99% A 4 ats	10(*2*)	10 × 2·5	7×10^{-3}	250	7×10^{-14}	550	Rigid extension ⅛ in. dia. ss × 15ft long max. confined gas volume.
		FC145/1000(*4*)	1·0 × 6·91	(a) ss 0·018 (b) ss 0·010	2	PET237 plug	A + 2% N_2 3 ats	290	145 × 8·25	0·18	250		300	Rigid extension $\frac{7}{16}$ in. dia. ss × 15 ft. long max., confined gas volume.
		FC538/1000(*4*)	1·8 × 23⅛	(a) ss 0·03 (b) ss 0·02	3·5	PET237 or Plessey Mk IV plug	99·99% A 3 ats	538	538 × 38·6	0·4	250	9×10^{-14}	550	Rigid extension ⅛ in. dia. ss × 15 ft. long max., confined gas volume.

(*1*) Fissile material is uranium containing 93% by weight U-235, deposited as oxide. (*2*) Also available with fissile coatings of Th-232, U-238.
(*3*) Also available by special arrangement with fissile coatings of Th,232 U232, U235, U238, Np237, Pu239, U233. (*4*) Based on AERE designs. Note: electrical terminations in all cases can be varied to suit individual requirements.

Fuel element fabrication

A report on the Vienna symposium, by R. S. Sharpe of the AERE, Harwell

FIFTY PAPERS were presented to the symposium, including six from the UK, and they fell under five main headings.

1. Characteristics of canning materials

Over half of the papers in this section dealt with the properties of zirconium alloys. One of the limiting factors in the use of zirconium alloys is the embrittling effect of absorbed hydrogen. Even with a tight control of the hydrogen content the tendency for it to migrate down a temperature gradient can cause local concentrations to built up at the cooler periphery of a can. Zircaloy 4, which has a lower nickel content than zircaloy 2(< 17 ppm), appears far less susceptible to hydriding effects. Both of these alloys have been specified in current Canadian reactor designs. Zirconium alloys with Nb and Sn are being studied, and the alloy Ozhennite 0·5 (0·1% Nb 0·2% Sn 0·1% Fe 0·1% Ni) favoured by the Russians comes into this category. Zirconium alloys with Al and Mo are being developed with improved creep strength, although from a corrosion standpoint they will need to be clad. From the Zr/Cu and Zr/Mo systems a suitable sheath material for a steam-cooled reactor operating up to 500°C may be found.

The welding and brazing of thin walled zircaloy tubing present difficulties, and improved argon arc and electron beam welding techniques were discussed. A magnetic force welding device that can produce zircaloy end weld in 1/60 s, thus obviating the need for an inert atmosphere, was described in a paper from the Hanford laboratories.

Some further assessments of S.A.P. alloys were given. These are sintered aggregates of aluminium lamellae individually coated by a natural oxide layer; they have small grain size, high strength and excellent creep resistance. A low oxide content (7%) would probably be preferred for reactor cans to give adequate deformability. As a canning material it is compatible with uranium below 500°C and with UO_2 up to 600°C, but it forms a low mp eutectic with magnesium and its alloys. Pressure welding techniques are necessary. Corrosion in pressurized water is very dependent on the physical form and source of the compacted flakes, and on the method of adding the corrosion-inhibiting Fe and Ni.

The attention to graphite reflected current German interest in low permeability graphite for the spherical fuel containers in the BBC/Krupp reactor design. It is proposed that the core of the densified graphite spheres will contain a mixture of uranium carbide and carbon with a U/C ratio of 1/45.

2. Fuel element fabrication

In the pressure bonding of the zircaloy-clad compartmented element for the second Shippingport PWR core, surface preparation is found to be very critical. Coating of the UO_2 with carbon or chromium provides a satisfactory reaction barrier during the bonding operation. The manufacturing processes for the Dounreay MTR 'picture-frame' elements were described, together with the Belgian alternative for this type of element which consists of casting the clad layer around the UAl_4 inserts. The design study by the Belgian Centre d'Etude de l'Energie Nucleaire again emphasized a growing interest in graphite. Blocks of graphite are pressure impregnated with uranyl nitrate, which is then transformed to UO_2 to give 0·014 g U/cc of graphite. The blocks are then canned.

A symposium on fuel element fabrication, with special emphasis on canning materials, was held in Vienna recently under the auspices of the International Atomic Energy Agency. There were some 200 delegates at the Conference representing 23 of the member states of the Agency.

Electron beam welding of end caps, swaging, spark machining and ultrasonic spot and seam welding were some of the newer techniques dealt with in detail. The co-extrusion of clad UO_2 elements was described in an American paper. This is a development of some significance since it shows promise of being applicable to a wide range of canning materials and of producing core densities very close to 100%. The core and cladding are heated to different temperatures so that their ductilities are compatible during extrusion.

3. Quality control and inspection

The need for more critical can inspection procedures was emphasized. A Swedish paper outlining experience with zircaloy tubing for the 1st charge for R3/Adam stressed the need to adopt a combination of inspection methods in order to ensure a consistently high quality. A Japanese paper, although specifically related to swaged products, served to pinpoint the current need to modify inspection philosophy to think in terms of attaining consistent and uniform microstructural detail, rather than merely in terms of freedom from macro defects. In this context the Harwell work on X-ray microscopy was relevant. With this technique microstructural detail, irradiation effects and cavitation were clearly revealed by the contrast provided by differences in X-ray absorption within the material.

4. Corrosion and radiation damage

The range of experimental CO_2 corrosion data that was presented showed how dependent corrosion rates were on the variables involved in reactor service, and how care was needed when extrapolating beyond the experimental conditions.

A detailed analysis of the element failures to date in the Calder Hall and Chapelcross reactors showed that they number 62 out of a total of 160,000. Harwell work relating to a more fundamental study of irradiation damage effects in canning materials was reported. Changes in the mechanical properties can be caused by the migration and clustering of displaced atoms and vacancies, and swelling and embrittlement by gas release and fission fragment penetration.

5. Economics and development trends

A cost analysis was presented which showed that improvements in fuel element lifetime provide the real key to lower power costs. Since a significant improvement in element performance with present fuels is likely to be achieved by better fabricating methods and more critical inspection procedures, further developments in these fields were strongly advocated.

A number of interesting development projects were described: Yttria additions are being made to UO_2 to increase its thermal conductivity; Plasma spraying of UO_2 on to stainless steel was being developed for plate-type elements; Ultrasonic compacting of UO_2 was giving consistently higher densities; Sodium infiltration of U powder was found to give a 'sponge' fuel with high conductivity suitable for high burn-ups; the Fe/Al system was being studied for a possible ductile canning material. Many of these developments are being done extramurally under USAEC contracts.

In this final article on health physics monitoring systems used on the more elaborate nuclear plants, the problems of data handling and data processing are discussed

Health physics instrumentation—5

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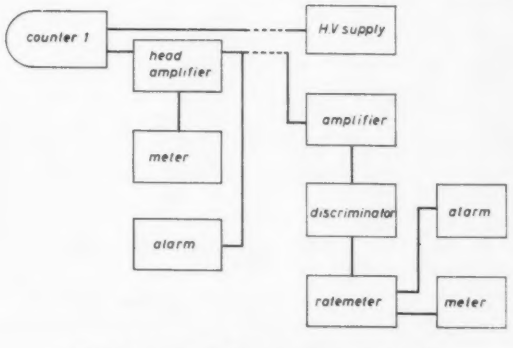
WITH THE LARGER installations, e.g. health physics instrumentation around reactor plant, chemical processing plant, neutron generator, or generator of ionizing radiation, it is necessary to monitor, say, the radiation dose rate at a number of points. It then becomes worth while to provide a central monitoring system which utilizes radiation detector components at each point where a radiation health hazard may arise. These parameters may be monitored continuously, or discontinuously in some suitable time sequence. Whichever method is employed the centralized system involves a data handling problem, and possibly a data processing problem as well, since (*1*) it is generally unnecessary to record all the readings of the various dose-rate measuring channels, providing the readings are within the normal (safe) limits. However, it is necessary to call the operating engineer's attention to any abnormality in the readings. This is usually done by providing alarm circuits which come into operation when the measured parameter falls outside the safe limits of working. It is also desirable to be able to check the sequence of operations leading to the abnormality. This latter calls for some form of memory system.

Installed health instrumentation

Figure 1 shows the circuitry associated with one counter in a typical system used at reactor plants for monitoring the fast neutron flux at the various locations where a radiation health hazard may exist. In this case all the monitoring channels are continuously employed, but in many cases it is possible to scan the various proportional counters in turn. Some economy in the apparatus in the central display panel is then possible. Note that in certain instances it is desirable to provide an indication of the counting rate (proportional to the radiation dose rate) at the detector location apart from the main indication in the centralized control room. This is also shown in Fig. 1.

In many health physics measurements it is necessary to provide facilities for measurement of dose-rate over a relatively wide range. It is possible to cover a wide range by using a saturated ionization chamber in association with a pentode electrometer in which negative feedback is applied to the screen grid. The anode current is maintained substantially constant over the operating range of the system, and selected electrometer tubes can be employed in this circuit to cover up to seven decades, e.g. 10^{-13} to 10^{-6}A. Sometimes the required range involves the use of inconveniently large ionization chambers to give the required ionization current, and it is then necessary to provide a part of the required measurement range using an ionization chamber/logarithmic amplifier system and a Geiger counter/counting-rate meter system for the more sensitive measurements. Such a combination system has become very popular, but does involve marrying the two parts of the system together and special problems of calibration.

Figure 2 shows a typical presentation unit containing all the electronic circuits, other than the head amplifiers and power supplies. As all the circuits are transistorized it is of relatively small dimensions. In this case three parameters are being monitored, namely (i) the dose in roentgens, (ii) the activity of the water supply, and (iii) the dose rate in roentgens per hour. As the range of the dose rate to be measured is from 10^{-4} to 10^{4} r/h, two measuring channels are provided in each case as explained above. One dose rate measuring channel uses a pressurized ionization chamber and an electrometer valve circuit, and the other uses a Geiger counter feeding a counting-rate meter circuit. Note that the two dose-rate channels are all switched together, and the switch in the right-hand bottom corner of the panel allows the associated six monitoring locations to be selected in turn as required. Similarly further channel selection switches are provided for selecting the appropriate detector locations as required for the measurement of the radiation dose and the water activity. In addition there are suitable trigger circuits for operating visual alarms if the water activity or the dose rate is excessive. In some cases aural alarms as well as visual alarms are provided, and for the larger installations it is worth while providing repeat alarm indicating units in locations where operatives have to work in addition to the indicator in the main control room. Such a repeat indicator unit is shown



Typical neutron flux measurement equipment (Fig. 1)

in Figure 3. The cover of the unit has been placed to one side to show the internal fittings.

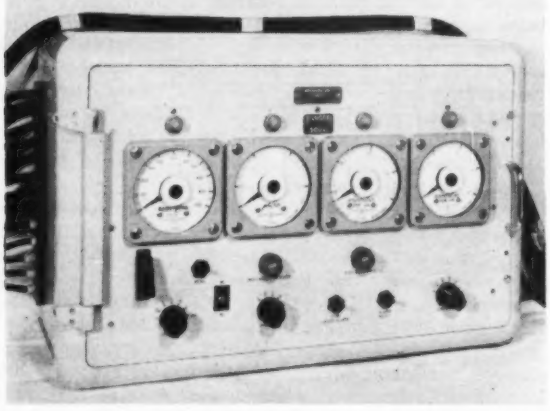
More elaborate systems

More elaborate systems of processing health physics measurements are also coming into use. One system sponsored by the French CEA (*3*) combines the pulse and the d.c. outputs from a single radiation detector to provide measurement over the required number of decades. This is shown schematically in Fig. 4. In this system the d.c. output set up by the detecting apparatus does not reach a value suitable for direct measurement until 1000 doses of gamma and beta rays have been detected. There are, therefore, two detector outputs, and a changeover from one to the other is provided when 1000 doses have been reached. The information given by the photomulitpliers in pulse form is employed up to 50,000 counts/s, which corresponds to 1000 doses. The first four decades are, therefore, measured by the pulse system, and the subsequent measurements above 1000 doses by the d.c. system.

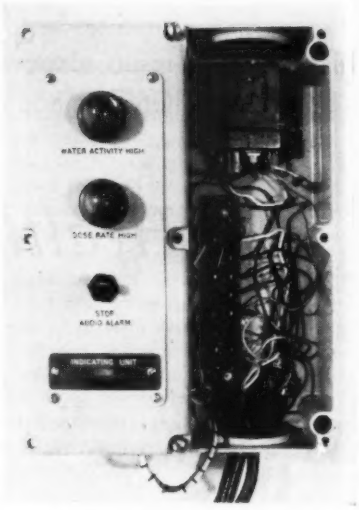
The coder provides a modulation of the constant telephonic frequency sinusoidal wave train. The period of this train represents the amount of the dose to within a multiplying factor which is itself applied separately on leaving the coder. In the central system the number of sinusoids contained in the signal is counted and the result multiplied by the appropriate multiplying factor.

In the central presentation system a scanning system is provided to deal with upwards of 60 monitoring positions and the information is stored in a 1-h memory. Alarm signalling circuits are also provided corresponding to three levels. These are (1) a level corresponding to a given preset dose, (2) a level corresponding to 10 times this level and (3) a level corresponding to 1000 times this level.

Systems of this type allow the designer a great deal of scope and there is room for much ingenuity. One interesting system marketed by Amican (Belgium) is called an Automatic Radiac Polymeter and is a dose-rate meter providing measurement over a range 1 microroentgen/hour to 1000 roentgens per hour on ten linear ranges. The apparatus automatically selects the appropriate range (according to the magnitude of ionization current at the output of the radiation detector) and the apparatus can be used in conjunction with a radio transmitter to transmit the dose rate (and, if required, other information) to a central control position.



Main presentation unit for health physics measurements (Fig. 2)



Alarm indicator panel (Fig. 3)

This system can obviously be extended to provide interrogating facilities at the central control position, so that the system can be used in association with a number of monitoring positions connected to the C.C.P. by land line. The operator can then interrogate each monitoring position as required and dose rate and other information can be transmitted automatically to the C.C.P. Alternatively the system can be made completely automatic by introducing an automatic scanning system so that each monitoring position is interrogated in turn and the health physics measurements recorded at the C.C.P. Systems of this sort are only worth while when a sufficiently large number of monitoring stations are required, or when some data processing of the measured data is required. Apart from the application to nuclear reactor plants and large radio-chemical plants, such systems find obvious application to fall-out reporting networks for civil defence purposes. The fact that an automatic system of this sort can be made to operate with the minimum of manpower is a real advantage. In the case of fall-out reporting networks it is usual to measure the gamma-radiation dose-rate at one metre above the ground to provide an index to the level of activity/metre^2 of fall-out.

Automation and film badge service

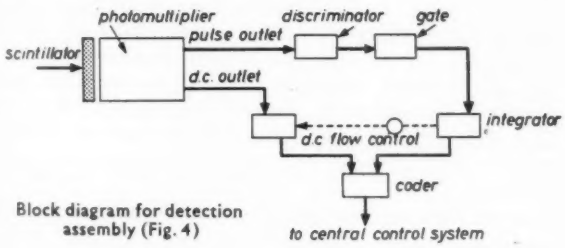
The most widely used method of measuring the dose received by a person is the film badge. Its chief advantages are cheapness, small size and the capability of integrating over long periods without significant loss. Badge processing after exposure is capable of a fair amount of automation and several systems have been evolved. Some of these have been developed especially for civil applications, but others such as the K. G. Foerstner and Company's 'Personal Identification and Dosimetry System' (*4*) have been developed for Service use. This latter is a special film badge and identification unit, which is designed as a flash dosemeter for individual issue, and is read automatically with an elaborate reader after development. The badge contains the nationality, registration number, medical data, etc., of the person to whom it refers. It also contains a film which is sensitive to gamma-radiation. The IDOS identity tag design appears to be basically sound. However, the use of a film badge technique for flash and personal dosimetry using a separate development and reading system has been

largely discarded by the US and UK authorities, because of the high operating costs and the large organisation required. Nevertheless the film badge technique is widely used in nuclear energy establishments for personal dosimetry and it may be that the use of automatic and semi-automatic methods as proposed for Service use could simplify procedures for civilian use.

Automation and radio assay

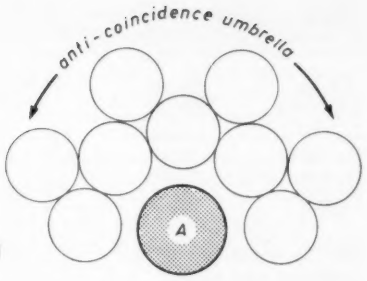
In many health physics measurements a radioactive sample is produced which requires to be assayed. In many cases the activity levels encountered are very low and very long counting times may be necessary. For this reason it is worth while using automatic methods of radio assay and sample changing (*5*), etc.

The form of apparatus depends very much on the precise method of measurement required, but involves the use of a sample-changing mechanism, which takes the samples to be assayed one tray at a time and inserts them in turn under a radiation detector (usually a Geiger counter or a scintillation counter) and removes the sample at the other side at the termination of the measurement. The detector with the associated electronic apparatus measures the number of radioactive emissions in a certain time, records the results and computes the disintegration rate (proportional to the measured counting rate) which is a measure of the quantity of radioactive material present in the sample, and this is also recorded. Machines of this sort are capable of working night and day with practically no attention and very soon pay for themselves.



Block diagram for detection assembly (Fig. 4)

One of the special problems which arises with this type of apparatus is the form to be taken by the controller. If time-controlled operation is used each sample will be counted for a certain pre-set time. This may be convenient if all the samples are of approximately the same strength, because then all the measurements are made to approximately the same statistical accuracy. However, if the samples are of widely varying activities the precision of measurement will vary widely from sample to sample. A more satisfactory method might then be to use count-controlled operation. All the samples will then be measured to the same statistical accuracy, but weak samples may be assayed for an unduly long time. A more satisfactory method (*6*) is to terminate the measuring period by a summation number determined by the sum of the counting pulses (from the detector) and the timing impulses (from a standard clock mechanism). If n is the total number of count + time impulses during a measurement time t, then the counting rate is $(n - t)/t = n/t - 1$. When the counting rate is high, the number n comprises a large number of count pulses from the detector and a small number of time impulses. This means that frequent recordings of the counting rate are made. When the counting rate is low, n is mainly comprised of time impulses and recordings are made infrequently. By a suitable choice of the number n and the frequency of the timing impulses it is possible to achieve a reasonable statistical accuracy for the higher counting rates (very active samples) without wasting time unnecessarily on the lower counting rates (weak samples). This is illustrated in Table 1. Here the timing impulses occur every second and $n = 10^6$.



Anti-coincidence shield (Fig. 5)

It has been pointed out recently by Cooke-Yarborough (*7*) (see also earlier article (*8*) in this series) that in the majority of health physics measurements, e.g. measurement of contamination, a large proportion of the measurements involve samples with no activity, whereas a small number involve samples with activities around the maximum permissible level, or higher. Given these circumstances Cooke-Yarborough suggests that the problem is largely that of determining whether a given activity is above or below a pre-determined level. He then proceeds to show that in this case much saving in counting time can result from using a new type of control system in automatic assay systems. So far this new system has not been employed on any commercial instruments, but it has obvious application to all measurements of weak radioactive samples.

It has been proposed to use this new control technique in connection with routine urine tests and other applications. In these cases the counting of the samples can be a lengthy procedure and it is often the case that the weakest samples are of very little interest, and as accurate measurement is only needed of the more active sample. It, therefore, follows that the rapid rejection of the weak samples could save a great deal of counting time. To do this AERE propose to employ a difference integrator* for the preliminary sorting of the samples into 'high' and 'low', only the former receiving a subsequent accurate count. According to one instance quoted by Cooke-Yarborough, samples are counted for 8 h and it is proposed to introduce a preliminary sorting operation which has an average sample time of 10 min for weak samples. The distribution of activity between samples is such that only for about one sample in 100 is it expected that the more accurate 8-h measurement will be required, and the average time per sample will thus be reduced from 8 h to about 20 min.

An alternative arrangement being considered by AERE is to use the difference integrator in parallel with the normal counting system to give a rapid indication if the sample activity is low (any 'high' indication being ignored). It is obvious that it could be used in this way, in conjunction with an automatic counting system incorporating an automatic sample changer, to curtail the counting of weak samples. It is probable that controllers for con-

* See article 3 in the present series p. 110, NUCLEAR POWER, June 1960.

TABLE 1 *Obtaining reasonable accuracy by a suitable choice of count + time impulses and frequency of timing impulses*

TIMING IMPULSES	COUNT IMPULSES	COUNT RATE, counts/s	STANDARD DEVIATION, △, %
10	9990	999 ± 9·994	1·00
100	9900	99 ± 0.995	1·005
500	9500	19 ± 0·1958	1·025
1000	9000	9 ± 0·0948	1·054
5000	5000	1 ± 0·014	1·41

trolling automatic systems based on this proposal will be produced very soon.

The parallel boundary method as proposed by Cooke-Yarborough not only provides a means of saving counting time without losing accuracy, but also provides increased accuracy without an increase of average sampling time. The original paper should be referred to for fuller details.

The measurement of very low activities such as are met with in these health physics operations allows advantage to be taken of this parallel boundary method. It is then an advantage for beta and gamma-assays to use a counting system with an anti-coincidence shield as shown in Figure 5. Here the detector *A* is shielded by an umbrella of other counters which detects mesons contributing to the background in *A*. Pulses from *A* which are in coincidence with the shield counters are cancelled. The importance of reducing the background count rate lies in the improved sensitivity (9) which can be obtained since the minimum activity which can be observed in a given counting time is determined by the background rate, and hence reducing the background rate offers the possibility of improved sensitivity. Full details are given in the reference quoted.

In the case of urine tests an alpha-activity assay is involved for checking quantitatively the presence of uranium and plutonium. An alpha scintillation counter with a very low background is employed (*10*) and again the use of automatic methods are worth while.

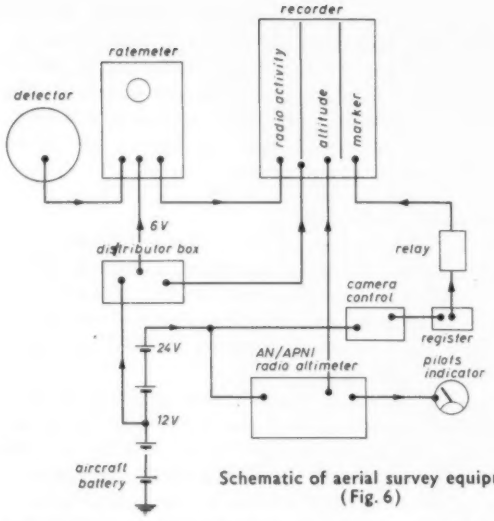
Recently (see article 3 of the present series) it has been shown possible to use selective gamma monitoring instead of alpha monitoring. This is particularly worth while when the hazard arises from inhaling or absorption of fissionable materials (e.g. Pu-239 and U-235) since selective gamma monitoring† offers the possibility of high sensitivity and the use of larger sample sizes and offers, therefore, the possibility of a simpler system.

Radiation monitoring of large areas

It will be readily appreciated that the routinely available monitoring equipment is inadequate to measure the distribution of contamination following an accident or other event that releases contamination over a wide area. The use of an aeroplane proved to be an effective aid in making rapid surveys of the country-wide contamination following the Windscale (*11*) incident. An Austin Autocar 145 was employed, and the equipment comprised a $4\frac{1}{8}$ in. diameter, 1 in. thick NaI (Tl) scintillator and a 35 mm air-survey camera for position plotting. Similar equipment has been used for aerial survey for uranium prospecting (*12*). Figure 7 shows the type of equipment which has been developed at AERE for this purpose and was employed in connection with the Windscale incident.

It is usual to fly at about 500 ft and at this flying height

† According to AERE in the case of the monitoring of Pu-239 and U-235 in process streams containing fission products the alpha assay method is to be preferred as it allows a higher concentration of fission products in the process streams.



Schematic of aerial survey equipment (Fig. 6)

the coverage of the aircraft is a strip about 1000 ft wide. This gives a considerable advantage in what can be achieved by a carborne equipment, but results in other advantages, e.g. independence of shadowing effects of buildings, trees, etc. However, it is necessary for the aircraft to fly at constant height; the use of a radioaltimeter (see Figure 6) allows corrections to be made for variation of altitude. Of course, if aerial surveys are to be used careful preplanning of flight patterns is necessary, and it is necessary to arrange background flights before the incident. The latter is necessary in certain areas as the background varies widely over different geological formations.

According to the results available to date aerial surveying is a valuable technique to be employed when the ground contamination produces a dose rate of about 75 μr/h at a height of 1 metre above the ground (*13*). It may be noted that for Cs-137 this corresponds to about 8 microcuries/m^2.

Apart from the aerial survey method it is possible, as has been mentioned earlier in this article, to use the remote telemetering method. It has the advantage that more precise measurements are possible, but has the disadvantage of providing only spot coverage. There appears to have been considerable development of the remote telemetering method in recent years (*14, 15, 16*), the use of transistors, packing techniques, and the use of single line pairs offering many new possibilities.

Acknowledgments

I am indebted to the Plessey Company for permission to use Figs. 2 and 3.

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Points from Papers

reports, meetings, conferences

BERYLLIUM MONITOR TRIALS

Reports of trials of the spectrographic beryllium monitor developed by the UKAEA were given in a lecture at Windscale by Mr. M. S. W. Webb of the AERE Woolwich Outstation to the Applied Spectroscopy Group of the Institute of Physics. The text of the lecture is given in *Atom*, July 1960, no. 45.

A description of the monitor is given on p. 104 of this issue of NUCLEAR POWER. In the final design of arc chamber, the air sample is drawn through a conical annulus which directs the air flow into the centre of the arc gap and along the length of the arc plasma. The design is such that the air velocity is low and the particles remain in the excitation zone for the maximum time (1 microsecond). To excite the particles efficiently, it was thought desirable to have a spectrographic source approximating in time-constant and plasma excitation a d.c. arc. This was achieved using a triggered a.c. arc operating under arc-like conditions. The rest of the apparatus is conventional.

A series of trials using aerosols of narrow particles size ranges was carried out to check the effects of particles size and the chemical form of the beryllium on the accuracy and sensitivity of the monitor. Tables 1 and 2 give the reported comparisons between the results obtained by the monitor and those from analysis of a filter pad placed behind the arc gap.

Results of field trials carried out with the cooperation of the ICI Metals Division at Witton, Birmingham, are shown in Table 3. Comparisons between spectrochemical analysis of filter pads and the monitor show the advantage of the latter in being able to detect high concentrations of beryllium over periods which would be too short to enable them to be detected by conventional techniques.

TABLE 1 *Comparison of results using beryllium powder (in $\mu g/m^3$)*

PARTICLE SIZE	ANALYSIS OF FILTER PAD	MONITOR
Fraction 1:	116	94
All particles over	23	25
40 μ	11	10
Most of the weight	28	26
carried by 85 μ dia.	54	75
particles	43	31
	29	38
	12	6
Fraction 6:	14	16
All particles less	35	33
than 25 μ dia.	71	62
	55	43
	1·5	2
	44	43
	31	24
	15	11
	13	12

TABLE 3 *Comparison of results obtained by the automatic monitor and filter samples under factory conditions using beryllium metal*

MONITOR	MEAN $\mu g/m^3$	SPECTROCHEMICAL $\mu g/m^3$
1 2 1 0 0 0 2 1 0 0	0·7	0·8
0 1 2 2 0 0 1 1 0 0		
1 0 3 0 0 3 0 0 0 0	1·8	2·3
0 0 0 0 0 1 3 0 4 21		
1 0 0 1 0 0 0 0 0 0	3·6	3·0
1 0 0 42 10 2		
0 0 0 0 0 0 5 0 4 53	4·8	4·2
4 2 10 3 2 7 3 0 2 0		
1 3 2 1 2 3 3 1 3 3	2·8	4·2
1 2 0 3 8 4 3 3 6 3		
0 2 5 1 3 2 1 0 0 1	1·5	1·2
0 0 1 0 3 0 3 4 1 3	1·5	1·7
0 0 8 3 3 2 3 1 3 2	2·5	2·5
2 7 2 4 1 3 0 3 1 0	2·3	2·8
3 1 1 9 1 7 7 4 3 0	4·5	3·8

TABLE 2 *Comparison of results for different beryllium compounds (in $\mu g/m^3$)*

BERYLLIUM HYDROXIDE		CRUSHED BERYLLIA CRUCIBLE		BERYLLIUM AMMONIUM FLUORIDE	
Spectrochemical	Monitor	Spectrochemical	Monitor	Spectrochemical	Monitor
19	12	14	10	51	37
52	44	62	32	9	16
37	27	19	13	4	5
23	13	2·5	2	56	82
62	46	23	13	51	45
13	9	33	24	11	10
18	14	2·5	2		
		59	36		
		36	26		
		18	14		

BSD SAMPLING AT CALDER

Low concentration at the sampling hole of the gaseous fission products from a can failure due to incomplete mixing with coolant, could make the damage less sensitive to detection. Investigations in a Calder Hall channel on this subject are described in a UKAEA report IGR-TN/W-1016 by T. Burgoyne, available from HMSO. Nitrous oxide was injected into the airflow in a model channel and detected downstream with an infa-red gas analyser. Mixing was slow along the elements, with incomplete distribution, largely due to poor circumferential mixing, after half the length of the channel. This is compensated for by good mixing between the top of the last fuel element and the sampling hole. The report says there would be no advantage in changing the present sampling position as the combined mixing effect ensures adequate detection efficiency.

BURN-UP DATA FROM OBNINSK

The May (1960) issue of Atomnaya Energiya (Atomic Energy) reports an investigation of spent fuel elements from the Obninsk 5 MWe reactor. The elements were irradiated for 104 days and stored for 1160 days. Remote examination showed that the diameters of the stainless steel cans increased from 14·11 $\pm$ 0·02 mm to 14·20 $\pm$ 0·02 mm.

Burn-up, determined from the activity of extracted Cs-137, had a mean value of 12·5%. This was confirmed by determining the uranium content at a point in the fuel element by using a mass spectrometer.

Table 4 shows the isotopic composition of the fuel element obtained from the alpha-radiation spectra and the number of spontaneous emissions.

TABLE 4 *Isotopic composition of fuel elements, in kg/tonne of uranium*

	Pu-238	Pu-239	Pu-240	Pu-244	Am-241
Experimental	$2{\cdot}54 \times 10^{-4}$	1·20	0·102	$1{\cdot}27 \times 10^{-2}$	$1{\cdot}86 \times 10^{-3}$
Calculated		1·17	0·100	$1{\cdot}36 \times 10^{-2}$	

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Analogue and digital

combining the advantages

The US National Bureau of Standards has been investigating a proposed analogue-digital differential analyser that combines the analogue advantages of high speed and continuous representation of variables with the digital capability for high precision and dynamic range. It represents dependent variables by two quantities, a digital number representing the more significant part, and an analogue electrical voltage representing the less significant part.

So far, an integrator and a multiplier have been designed. In general, they consist of one or more of the following units: an input digital register, a register for accumulating digital results, a digital-to-analogue converter, a conventional analogue integrator, a resettable analogue integrator, an analogue summer, and a comparator. These basic units can be constructed from electronic digital and analogue circuits in present common usage. Analogue-to-digital converters are not required for this system.

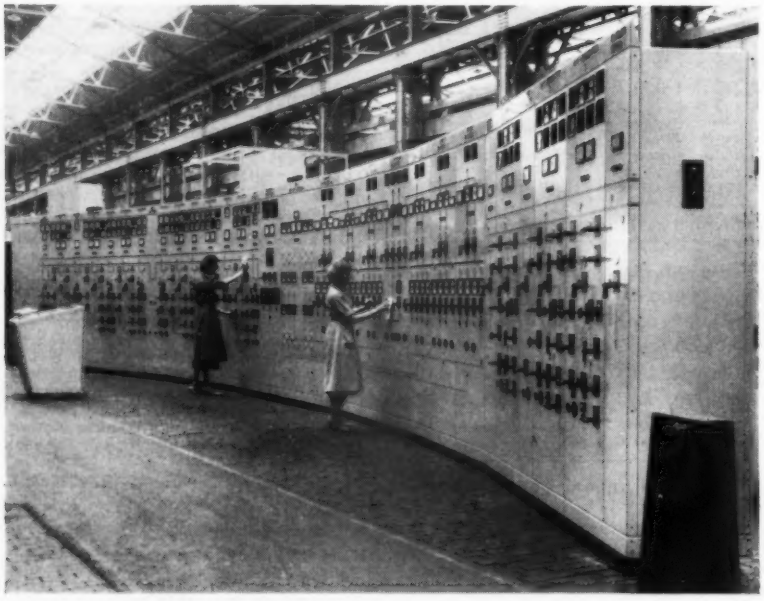
The over-all analyser is designed so that the time period ($\triangle t$), during which the number in the digital registers do not change, is made as small as possible, consistent with component limitations, in order to permit the maximum number of such periods.

In a somewhat similar field, but with more stress on flexibility and range of problems, is the new RADIC system developed by Redifon. This is a fully integrated assembly of analogue and digital sub-units designed to enable complex calculations, simulation and data reduction to be accomplished with the stability and ease of operation of a digital computer, combined with the speed and simple programming of analogue computation.

Basically the system comprises an assembly of d.c. drift-corrected amplifiers, electronic multipliers and diode-network function generators, operating on a relatively fast time scale. Numbers and physical variables are represented by voltage levels. Digital devices are used for feeding the analogue with numerical data, as well as for the storage of data.

The magnetic-tape digital storage system helps to extend the field of use to complex types of input data which the normal analogue computer is unable to handle. Containing two tape decks, a digital encoder and a digital-to-analogue converter, the storage system takes the form of a separate cabinet which enables it to be taken to a remote site for recording purposes.

The RADIC system can be used for such problems as heat exchanger and reactor analysis and design and for statistical, flow-line and systems analysis and linear programming.



HINKLEY POINT CONTROL The main control board for the Hinkley Point nuclear power station has been completed at English Electric's Stafford works and is being despatched to site. The 33-panel board, which is 52 ft long, will control the main generators, the variable frequency auxiliary turbo-generators, the d.c. auxiliaries and the fourteen 275 kV 7500 MVA air-blast circuit breakers in the outdoor switching station. The six main generators, which are hydrogen cooled, have been designed for a normal output of 87 MW at 15 lb/in^2, but by raising the pressure to 25 lb/in^2, maximum output has been increased to 93·5 MW. Generation voltage is 13,800 V and this has been stepped up by generator transformers to 275,000 V for transmission. The three 33 MW V/F generators, one of which acts as a standby, are to be used to supply power to the a.c. motors driving the Co_2 air blowers

Reducing the static charge

panels for computers

Glass panels, that carry off electric charges built up in equipment such as large computers, have been developed by Corning for use as windows and transparent partitions.

The shield consists of a panel of borosilicate glass coated on one side with a thin ($\frac{1}{16}$ millionth of an inch), transparent metallic film, permanently fired. This coating intercepts the radiated interference, which then can be grounded by such devices as conductive tape, carbon button, or clamp-on spring.

The coated panel transmits 70% of visible light and the glass resists thermal shock and corrosion.

Triga elements modified

stainless canning

General Dynamics propose to modify their fuel elements for the Torrey Pines Triga reactor. Canning material will be changed from 0·030 in. thick aluminium to stainless steel of 0·010 in. or greater in thickness. The fuel rods are to be composed of two or more sections rather than a single 14 in. rod; the original 1·4 in. diameter remains unchanged and the total length will not exceed 14 in. Fuel rods will

contain an axial hole of up to ½ in. in diameter with the hole blocked by non-fissionable material such as graphite, zirconium or stainless steel.

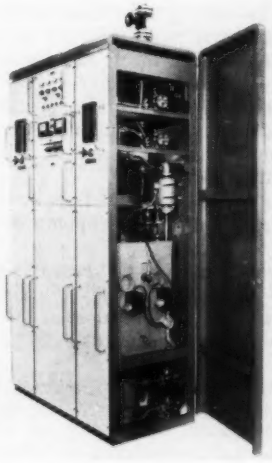
No more than a total of twelve redesigned elements will be loaded into the reactor at any one time.

Fuel for small reactors

niobium-uranium alloys

Research on niobium-uranium alloys by the USAEC indicates a promising use in future compact reactors, of the type likely to find use in portable electrical power generators, space craft propulsion systems, and in ship propulsion systems, where a long-life core and corrosion resistance are prime considerations.

A niobium alloy containing 20 weight per cent uranium showed excellent tensile strength and hardness at temperatures in the 1600°F range. In addition, it has other desirable qualities—high thermal conductivity, good corrosion resistance—and it also retains fission gases. Fabrication techniques present no problems for niobium alloy can be prepared with little or no difficulty by a consumable-electrode arc-melting technique.



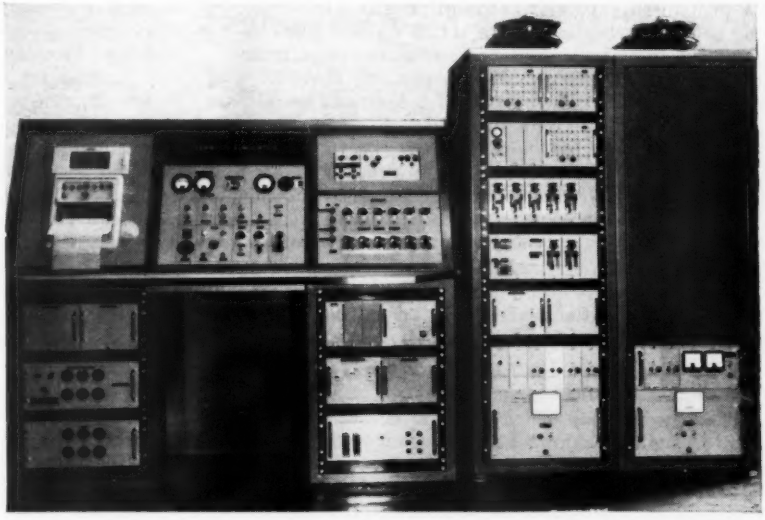
BURST SLUG DETECTION Fission product monitoring (BSD) equipment, marketed by Plessey Nucleonics, is being installed at the Dido and Pluto reactors at Harwell, the DMTR reactor at Dounreay and at similar materials testing reactors abroad. The equipment comprises a 25-way gas selector valve block, a reciprocating rod type precipitator, a gas ionization detector system, electronic counting equipment and power supplies. As the carrier gas, and the associated fission-product gases (if present), carry over through the selector system a certain amount of heavy water, this is condensed with the aid of a refrigeration system and subsequently returned to the reactor

Analogue reactor computer

multi-purpose facility

An analogue computer, MARC, which combines special purpose equipment tailored to reactor design studies and general purpose computing units, has been developed by Miles Electronics. For normal use, all units are wired as a reactor loop but, by the removal of a few shorting links, the loop is broken allowing the general purpose units to be programmed for the solution of general problems.

The special purpose equipment includes a kinetic unit with automatic rescaling over 10 decades and logarithmic and linear channels; a photoneutron unit; and I-135 and Xe-135 poisoning integrators. The general purpose system comprises: 30 high gain drift connected d.c. amplifiers; 16 coefficient units; 12 integrator units; and 3 non-linear function generators, each providing sixteen break points.



MARC combines the advantages of a reactor simulator and a general purpose computer. It was recently demonstrated at the Rome exhibition and units are being installed at the Dusseldorf Reactor Centre and at Rome University

New 12·5 GeV accelerator

Argonne extends facilities

The Argonne National Laboratory is to be equipped with a £M10 zero gradient proton synchrotron that will accelerate particles to energies of 12·5 GeV. One of the most difficult problems was the fabrication of a 5000 ton ring of magnets, composed of 40,000 half-inch tapered steel sheets glued and bolted together, the whole requiring the utmost precision.

The ring, which will be 200 feet in diameter, is formed by eight magnets, each weighing 600 tons and composed of 16 subassemblies of steel sheets. Insulation will be made by fibreglass layers, twelve-thousandths of an inch thick, and cementing by use of epoxy resin. The relatively small circle of magnets, resulting in a saving in steel amounts, has been made possible by the high magnetic field strength. The first sections are expected at the end of 1960 and the whole project is scheduled for completion by 1962.

High temperature metals

alloys under development

Alloys of niobium, aluminium and zirconium are under development at Battelle that should lead to improved high temperature strength. Zirconium alloys containing combinations of iron, nickel and chromium appear promising for applications in steam at 900–1000°F, as do copper-molybdenum-zirconium alloys.

Niobium alloys with almost equal corrosion resistance as Zircaloy-2, but with greater high-temperature strength and a higher neutron cross section, include a 12 atomic per cent vanadium alloy; a 28 atomic per cent titanium; 6 atomic per cent chromium alloy; and alloys containing over 45 per cent zirconium. Aluminium alloys containing up to 1% iron and/or nickel, plus smaller amounts of beryllium, titanium, and zirconium, have shown improved corrosion resistance and are now being considered for use in pressurized water reactors.

The underwater decanning plant at Marcoule has proved itself to be satisfactory and reliable

Decanning fuel elements from Marcoule

by G. DELEUZE and G. PETILLAT, Société des Forges et Ateliers du Creusot, and R. GUILLOTEAU, CEA

THE FUEL ELEMENTS from the G2 and G3 reactors are bars of natural uranium canned in light alloy. The length of the cylindrical bar is 282 mm (11·10 in.) and either 28 or 31 mm (1·10 or 1·22 in.) in diameter according to the position in the reactor. Weights are respectively about 3·216 kg (7·09 lb) and 3·960 kg (8·73 lb). Each bar has a spiral rectangular groove 0·3 mm (0·012 in.) deep at a 12 mm (0·47 in.) pitch.

The canning material is magnesium-zirconium alloy with 0·4% Zr and there are 16 longitudinal fins. The tube is closed at both ends by caps of the same material.

Irradiated elements from the reactor are placed in batches of four in cases made of A5 aluminium which are 70–73 mm (14·57–14·67 in.) in diameter and about 1385 mm (54·53 in.) long. After sealing, they are put in the cooling pond and subsequently taken for decanning.

Working conditions

The large number of cartridges to be dealt with means that decanning has much in common with continuous production processes and is carried out entirely mechanically. Special difficulties are raised by the irradiation, however: on the one hand, the operating personnel cannot be exposed to the danger of radiation or contamination, and on the other hand, the cartridges are sometimes deformed. It is necessary, therefore, to protect operating personnel, and at the same time allow them to observe the operation of the machinery, so that they can immediately intervene if anything goes wrong.

The general arrangements, together with the main principles of water-shielded decanning, were partly established by the CEA through a pilot plant at Marcoule which used irradiated fuel elements. They were confirmed by numerous tests made with full-size inactive cartridges.

Decanning proper is carried out in two stages: preliminary slitting of the can along two diametrically opposite longitudinal lines, and extrusion of the bar of uranium through a die.

The installation in general

The water-shielded mechanical decanning installation consists of two parallel but separate lines served by a delivery channel leading from the cooling pond. Each line comprises a pond where the cases are opened; a decanning pond, and a storage well for decanned bars. All these ponds can be isolated by means of sluice-gates.

The machines are mounted on fixed pedestals at the bottom of the ponds. Most of their actions are produced by hydraulic rams supplied through flexible pipes so that the machines can easily be withdrawn from the water if necessary (see Fig. 1).

The handling of the cartridges and the removal of bars, pieces of cans, and halves of cases, are carried out by operators moving on gantries over the ponds. Water-telescopes enable all the machines and the handling equipment to be kept under continuous observation, and the movements of the hydraulic rams are repeated on control panels by means of sealed flexible transmission lines.

Among the precautions taken by the CEA to avoid spreading of contamination, were: continuous filtration of the water in the ponds; localized filtration, by means of suction heads drawing in the water around operational points; ventilation of the space between the gantries and the surface of the water in the ponds and using water instead of oil in the hydraulic rams. If there were an escape of oil, drops carrying contaminants in suspension might rise to the surface of the water. Also, an escape of oil would adversely affect visibility through the water.

Pond for opening cases

Each pond is provided with a machine for cutting open the aluminium cases. Handling is by means of removal channels, a hydraulic transporter for the empty cases, and special poles.

The cases are opened by cutting each case across the middle with it in the horizontal position; then drawing the two halves apart and tipping them until they are vertical, thus causing the cartridges to fall out.

The cases are cut by sharp-edged wheels—a method of cutting which is considered preferable to milling or sawing because no metal fragments are produced and no water is churned up by rapidly rotating parts.

During cutting, the case has a tensile load applied to it by the action of two rams acting on the tipping devices in opposite directions.

When the clamping jaws of the tipping devices are released the empty halves of the case fall into another removal channel. The cartridges and the halves of the case are directed towards the appropriate channel by a hydraulically operated selector flap.

All the rams carrying out these various movements are controlled semi-automatically from a panel on the gantry above the machine.

The operator can turn, by a ratchet-lever, a spindle carrying cams which actuate a series of valves controlling the admission of hydraulic fluid to the rams and its release. Repeaters on the panel for ram movements allow an electrical safety locking system to lock the camshaft against further movement if there is any defect. The valves can be operated separately by manual control levers in a different order from that of the programme cycle, if desired.

The decanning pond

The can slitting machine The object of this machine is to cut grooves or slits along two diametrically opposed longitudinal lines on the can so as to reduce the amount of pressure required to extrude the bar from the can. Slitting by means of sharp-edged disks was preferred to milling or

sawing for the same reasons as in the case-opening pond.

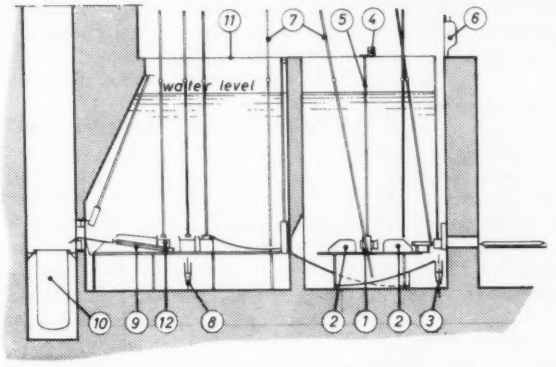
The main part of the slitting machine is a detachable cutting-disk unit provided with two cutting disks and two guide disks, all freely rotatable on their spindles. The cartridge is placed on two supporting members with the aid of a rake-headed pole, so that it lies in the axis of the machine. A ram, controlled by the operator by means of a three-way manually-operated control valve, actuates a punch which forces the cartridge into the cutting-disk unit, where the two cutting disks, pressed towards each other by spring washers, cleave the can as it passes between them.

The extrusion machine Extrusion is effected by applying a ram-actuated punch to one end of the cartridge with the can resting, at the other end, on the edges of a die. The diameter of the ram is less than the inside diameter of the can, so that it only presses on the bar of uranium. The diameter of the die is such that it holds back the can but allows the bar to pass through. The punch and the die unit can be remotely handled.

After slitting the can, the cartridge is placed in the extrusion machine by a handling pole fitted with tongs, so that one end of the cartridge rests on a support integral with the die mount and the other end rests in a centering device. The operation controls the ram using a three-way control valve similar to that used on the slitting machine.[1] In this, the spring-loaded centering cone slides over the end of the cartridge; the punch then comes into contact with the endcap of the cartridge and brings about extrusion of the bar. Because of the grooves cut along the can by the cutting disks, extrusion of the bar causes the can to fall apart.

Endcap removing machine Sometimes an endcap sticks to the end of a bar of uranium. In this case it is removed by a guillotine-like device.

Removing the uranium bars A retractable spout provides a connexion between the decanning pond and the storage well, by way of one of the sluice gates. When this spout is in position, the decanned bars are moved, one at a time, in front of a plunger attached to a ram, which pushes them into the spout in groups of four until they drop freely into a storage basket. This operation is manually controlled.



1 cutting head
2 tipping devices
3 hydraulic transporter for removing empty cases
4 electric motor and reduction gear
5 driving shaft
6 control panel
7 pivoted handling poles
8 hydraulic transporter for can removal
9 device for removing bars
10 basket for bar storage
11 gantries for operators
12 endcap removal machine

Fig. 1 Schematic view of the installation

Hydraulic power supply system

The hydraulic power supply system delivers fluid under pressure to the various rams in the decanning lines. It consists of a low pressure circuit (10 kg/cm², 142·2 lb/in²) for supplying the low power rams, and a medium pressure circuit (30 kg/cm², 426·7 lb/in²) for supplying the rams used for cutting and extrusion. The motive fluid is demineralized water with about 5% by volume of pure glycerine added to it.

A case is presented for the separate consideration of the hydrodynamic and thermal aspects of nucleate boiling

A gas-liquid analogue of nucleate boiling

by G. B. WALLIS, B.A.(Cantab), S.M. (MIT), Research Fellow, AEE, Winfrith

BOILING IS A COMPLEX phenomenon involving both thermal and hydrodynamic processes. A complete analysis requires the solution of the equations which govern both processes. The hydrodynamic problem may be solved on its own only if the boundary conditions imposed by the thermal processes can be specified. If these boundary conditions can be accurately simulated in a purely hydrodynamic system, the problem may be attacked by an analogue approach.

A gas-liquid analogue, using a porous medium as the generating surface, makes it possible to devise simple experiments using two discrete components to verify theoretical predictions, and to throw light on many aspects of the boiling process.

Two-component systems have the advantage that each phase is distinct and recognizable; it maintains its identity, and flow rates can be measured without confusion. A finer control over the generation process can be achieved and many uncertainties inherent in heat-exchange devices such as surface temperature distribution, heat losses, hot spots etc. can be eliminated.

The hydrodynamic aspects of boiling have been analysed by many authors (*1–6, 10*), of whom some have tried to describe certain boiling phenomena on hydrodynamic grounds alone.

Few experiments have been conducted to test how far the hydrodynamic aspects of boiling may be separated from the thermodynamic aspects and, though numerous experiments (*7*) have been undertaken under the general heading of two-phase flow, little work has been done in the field of the direct simulation of boiling using two-component systems. The problem has been the develop-

SYMBOLS

$\triangle P$ = Pressure drop	r_o = radius of mouth of cavity
T = Temperature	r_m = minimum radius
$\triangle T$ = Wall superheat	v_{fg} = volume of evaporation
h_{fg} = Enthalpy of evaporation	σ = surface tension
r = radius	

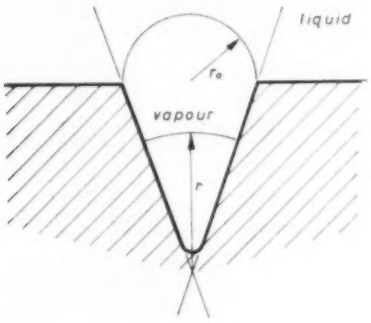


Fig. 1 Idealized conical cavity

ment of a technique for simulating the generation of bubbles at a surface. Two phases may flow together in an infinite variety of ways and one cannot expect to simulate boiling phenomena accurately unless the *initial* and *boundary* conditions are the same in the analogue as in the boiling system itself. For this reason, most of the results derived from air–water and similar systems are often misleading, if applied indiscriminately to systems in which boiling is actually taking place.

Surface boundary conditions

Boiling Boiling from a surface is not a purely random phenomenon but tends to take place around certain favoured nucleation sites. These points may consist of patches of impurities, gas absorbed at faults in the crystal lattice, or surface defects such as pits and cavities (*7, 11, 12, 13*). It is, of course, impossible to describe the geometry of all the cavities on a surface in full, and a statistical description of surface conditions is necessary in the case of commercial surfaces. Nevertheless a proper understanding of the behaviour of a population of cavities may be approached from a study of single cavities of a simple geometry. Such an approach was used by Griffith and Wallis (*14*) who made conical indentations in a surface and observed nucleation from them (Fig. 1). Good correlation with theory was obtained in their experiments.

Bubbling To simulate the generation of bubbles in boiling, use may be made of sintered porous materials. These materials consist of a vast number of minute metal (or other) particles formed in a mould, pressed together and heated until they join. Pore sizes are distributed statistically and shapes also are random. When gas is pumped through the material into a liquid, bubbling starts at preferred sites, the nucleation centres. The behaviour of such a system may be compared with the behaviour of a boiling system.

For a mathematical analysis of the bubbling process, an idealized pore is considered. It consists of a nozzle or duct of varying diameter but always of circular section (Fig. 2). As with a boiling surface, a statistical analysis is necessary for a complete description of the surface.

Nucleation

The initiation of boiling from a cavity and the start of bubbling from a nozzle or from a pore in a porous material are almost identical processes.

Boiling Griffith and Wallis (*14*) have shown that nucleation from a cavity can be explained in the following way:

If a bubble exists in a cavity as shown in Fig. 1 it is subject to excess pressure due to surface tension effects. The actual value of the excess pressure depends on the cavity geometry and on the contact angle. For simplicity a contact angle of 90° and a conical cavity are considered. In this case, the excess pressure in the bubble is:

$$\triangle p = 2\sigma/r \qquad (1)$$

In the absence of superheat or an extraneous gas such as air, the bubble will be unable to exist and collapses. If the bubble is in equilibrium there must exist a superheat given by the Clausius-Clapeyron relation:

$$\triangle T = \frac{T v_{fg}}{h_{fg}} \cdot \triangle p = \frac{T v_{fg}}{h_{fg}} \cdot \frac{2\sigma}{r} \qquad (2)$$

When the cavity is already active and contains vapour, the value of r to be substituted in equation (2) is the mouth radius r_0. In a completely wet cavity a very high value of T is needed to initiate boiling. In practice, the cavity is activated by a small bubble of air or by vapour which spreads from a neighbouring cavity and becomes trapped by the turbulence set up by the boiling process. For clean surfaces and pure liquids very high superheats may be obtained before boiling will begin.

During a boiling experiment, the number of active cavities is determined by the superheat and by the distribution of cavity sizes, dependent upon the surface finish of the material.

Bubbling If an interface exists in a pore, as shown in Fig. 2, there must be an excess pressure in the gas supply given by equation (1). If no excess pressure is supplied and the liquid wets the surface, the air will be driven back to the entrance to the pore. For the interface to be in equilibrium an excess pressure must be supplied. When a completely active pore is passing a stream of gas, the value of r to be substituted in equation (1) is the mouth radius r_0. The pressure required to activate a completely wet pore is given by equation (1) using the minimum pore radius r_m. If the pore contains a neck or waist, high pressure may be necessary to initiate bubbling.

During a boiling experiment the number of active cavipores is determined by the excess pressure and by the distribution of pore sizes on the surface of the material.

In both boiling and bubbling experiments nucleation phenomena may be described by the same basic equations.

Bubble growth

Boiling Several attempts to evaluate bubble growth rates in boiling from thermodynamic reasoning have been made (*17–20*). The usual approach is to write thermal conductivity relationships with conveniently assumed boundary conditions and to try to solve them. Reasonable success has been achieved. Most solutions (*18–20*) have been based

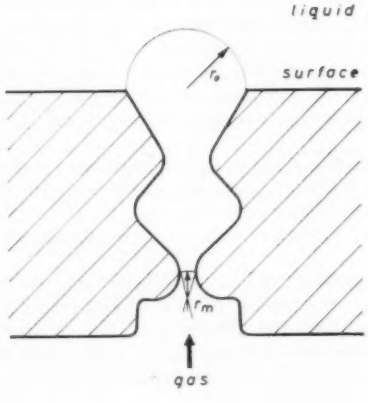


Fig. 2 Idealized sintered metal pore

upon the growth of bubbles in a uniformly superheated liquid, but it is unlikely that the results are wholly valid for the growth of bubbles in the temperature gradients existing in a thermal boundary layer. Griffith (*17*) tried to make allowances for the temperature gradient near the wall by using a linear approximation.

Because thermal conditions in the layer of fluid near the heated wall are fairly chaotic as a result of violent turbulence induced by the departing bubbles, it seems extremely doubtful whether the bubble growth problem could ever be solved exactly. In any case there are bound to be statistical fluctuations in the results. Any theory is bound to contain some elements based on the correlation of observed data.

In reference (*9*) Staniszewski's results (*16*) are used to show that the major part of a bubble's history in bulk pool boiling can be approximated by a linear increase of volume with time. This conclusion is entirely empirical and differs from the majority of growth rate theories which predict that the bubble radius should increase as the square-root of the time (*18–20*). However, the linear relationship has the virtue of an experimental basis. Statistical thermal fluctuations are only manifested as changes in the slope of the volume–time curve. Statistical hydrodynamic fluctuations are displayed in the lifetime of the bubbles and are due to the premature removal of a bubble by the turbulence in the boundary layer. The linear nature of the growth curves remains invariant. The break-away time is determined by hydrodynamics alone.

Bubbling Once a bubble has begun to grow, the excess pressure necessary to overcome surface tension soon becomes negligible.

With small diameter pores, the pressure drop during the growth process is determined solely by the pressure drop required to force a given flow rate through the pore. For a given pressure drop, this flow rate will be constant and a plot of volume against time will be linear (*9, 15*). The slope of the curve will be governed by the pressure-drop characteristics of the pore.

The time taken by the bubble to break away from the surface in still fluid is dependent upon the properties of the fluid, the pore geometry and contact angle. When several bubbles are agitating the fluid, turbulence is set up and a statistical spread is introduced into the break-away time.

The linear nature of the post-critical growth process is confirmed by experimental evidence in the case of both boiling and bubbling through a nozzle. The break-away times in each case are in fair agreement and individual variations can be explained by statistical arguments.

The hydrodynamic phenomena in both bubbling and boiling bubble growth appear to be the same and can be described by the same equations once the relevant parameters are defined. The actual mechanism of vapour or gas generation is irrelevant so far as the hydrodynamics are concerned, so long as the bubble growth curves are similar in the two cases.

TABLE 1 *Similarity between bubbling and boiling phenomena*

PHENOMENON	DEPENDENT VARIABLES	DETERMINING FACTORS BUBBLING	BOILING
Nucleation	Number of centres	Excess pressure $\triangle P$, poresize and shape, surface tension	Wall superheat $\triangle T$, cavity size and shape, surface tension
Bubble growth	Growth rate (linear)	$\triangle P$ acting upon pore diffusivity, variations due to pore characteristics	$\triangle T$ acting upon liquid thermal diffusivity. Statistical variations due to turbulence
	Growth time	Hydrodynamic. Statistical variations due to agitation	Hydrodynamic. Statistical variations due to agitation

Departure from nucleate bubbling/boiling

If the departure from nucleate bubbling is due to the interference and agglommeration of nearby bubbles (*3, 21, 22*), it might be expected that the hydrodynamic relations governing this phenomenon would be the same in bubbling and boiling systems.

Once such a transition point is reached, the analogue breaks down because the mechanism of gas (vapour) formation ceases to be similar.

Nevertheless, at very high gas flow rates it could be expected that the gas would form a blanket over the surface which becomes dry. If such a flow pattern could be observed, the hydrodynamics governing the escape of gas from the immediate vicinity of the generating surface might be analogous to those describing the escape of steam in film boiling.

Conclusions

The points of similarity between bubbling and boiling phenomena are summarized in Table 1.

A close parallel has been shown to exist both in the nucleation process in the growth of a bubble while still attached to the surface, and in the mechanism of departure. It should be possible to reach a better understanding of these phenomena by performing suitable experiments with two-component systems.

No further claims are made for the analogue. The further growth of a steam bubble after leaving the heating surface (*23*) cannot readily be simulated by a two-component system. Heat transfer in boiling cannot be directly compared with the rate of bubbling, since the increased heat transfer in boiling systems is due primarily to the increased agitation in the boundary layer rather than the latent heat carried away by the bubbles (*23*).

Acknowledgement

Condensed from AEEW-R.28 ' The Analogy between the bubbling of Air into Water and Nucleate Boiling at Saturation Temperature ' by kind permission of AEE Winfrith Heath.

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Cross Section by GRACCHUS

PERHAPS IN no small manner an indication of the Government's thinking on nuclear power was the way the Minister of Power, Richard Wood, described the recent revisions in the power programme in the House of Commons. On the day 'the' White Paper was published, he said: 'Rather than being a cut-back, it is a deferment of the acceleration which was planned in 1957'. I understand he was apparently surprised by the subsequent laughter.

There must also have been some head-scratching among the consortia design teams after Sir Christopher Hinton's aside at the Press conference on the revised programme. He was speaking about the Advanced Gas-Cooled Reactor and at the end of his comments casually mentioned that Oldbury might be an AGR, though it was unlikely that so large a station would be chosen for the first commercial AGR. This type of statement will make everything very clear, for the consortia have been informed that Oldbury is to be Magnox canned.

Comments in the newspapers on the announced cuts took various lines. Most felt that the decision was justified, though the *Guardian*, as did NUCLEAR POWER, wondered whether by slowing down construction 'technical progress towards more efficient types of nuclear reactors might be delayed'. *The Times* pointed out that the comparison of costs of electricity from nuclear and conventional plants assumed that the capital cost should be calculated on the gilt edge rate of interest because the Electricity Authority borrowed at that rate. 'This is a wholly inappropriate method as has been widely recognized', the leader stated. Other papers, such as the *Scotsman*, felt that the decision 'must strengthen fears that the Government has given way to pressure on behalf of coal'.

Far be it from me to suggest anything like that, but it did strike me as incongruous that the cuts should come after the United States has drawn up a ten-year plan for research and development; when Frank Pittman, the director, and U. M. Stabler, senior assistant director, of the US AEC's Division of Reactor Development, should have said in April '. . . it will be possible to achieve economic nuclear power in high cost areas of the US by 1968 with continued aggressive development of light-water cooled and organically cooled reactors'. The relevant word seems to me to be aggressive.

THE PLASMA gun, entropy and skew trapping devices, Perhapsatron S-5, Zeus, fast spark switches, fast condensers, Scylla, the orthonogonal pinch and Ixion were inspected by five Soviet scientists who recently toured US controlled thermonuclear research installations. I understand they retaliated by describing their own work in the same field. There is also a rumour that three interpreters retired 'hurt'; two with nervous breakdowns and one, who was quietly incarcerated after suddenly causing havoc among the distinguished guests by applying what he jovially called his variation of the orthonogonal pinch.

THE ACRIMONIOUS debate as to whether nuclear merchant ships will be economic or not has, I think, been put into perspective by Louis H. Roddis, chairman of the US Maritime Research Advisory Committee. Speaking at the recent ship's conference in Philadelphia organized by Atomic Industrial Forum Inc., he stated: 'It should be remembered that the first Savannah was probably not viewed as an economic or commercial success either . . . steam power was, and is, much more expensive than sails'.

I SAW ONLY two representatives from the UK mingling among the hundred-odd Europeans at the recent ceremony inaugurating work on the Eurochemic establishment. But if Dr. Rennie of the Dragon project and Mr. Peirson of the UKAEA compared the expanse of dead waste land lying before them with the thriving UK plants, they may well have thought that Britain would have little to gain by joining the project. So far, only the walls of one small block have been built and it will be some time before any of the Eurochemic scientists move across the canal from their makeshift home in the Mol Research Centre. They have been working there for over two years while the grindingly slow process of organizing an international company continued; until the tenth country concerned ratified the agreement a year ago, thus giving the company a legal existence at last, the necessary money had been advanced by the European Nuclear Energy Agency. In the circumstances, the continued optimism of the scientists was a surprise to me. 'It's difficult to do much here', one of them confided as we walked round the rather meagre laboratories rented from the Mol Research Centre, 'but it won't be long now before we really get under way'. I also heard several regret the UK's absence from the project. In practice, the AEA and individual British scientists are apparently most helpful when asked, and the supply of technical information would not be materially affected if the UK bought its way in officially. 'But we would like to have the UK with us', Dr. Rometsch, the Technical Director, told me. It is evidently the psychological effect which counts. But unhappily, this is just one more continental enterprise from which the UK has kept insularly aloof.

ANOTHER BLOW for commonsense about radioisotopes, albeit through the medium of a radio play which contained the largest number of footsteps I have heard, was struck by the BBC with their skilful presentation of Stephen Grenfell's play 'The Herd'. The plot, briefly, is that a private firm builds a radioisotope plant in a small country town. The locals resent this; to them it is out of the normal and almost witchcraft. Their resentment boils over into a near riot when an experimenter contaminates his family and all around him by carrying an exposed gamma source home. The ending was happy; an oration by the director of the establishment sent everyone home. Apart from its entertainment value, the play seemed to me to bring home again to the public what a lot of nonsense is talked about radiation.

New Product Survey

EQUIPMENT · INSTRUMENTS · MATERIALS

★ *For further information on any item, circle the appropriate number on the reply card facing page 138.*

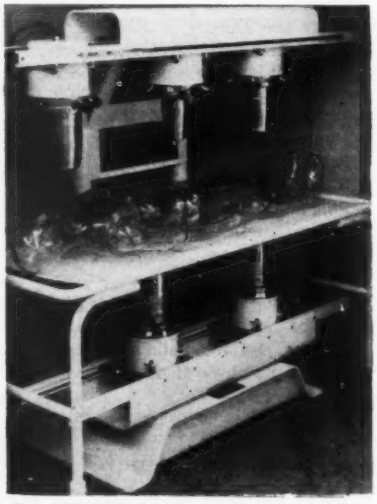
RADIATION MONITORING

automatic body scanning

Nuclear Enterprises have produced two versions of a whole body monitor for radiation detection. The NE8102A assembly employs four 4½ in. dia. × 2 in. thick NaI(Tl) crystals which are viewed by four EMI9530A photomultipliers mounted on an annular ring, automatically scanning the whole length of the patient's body.

The NE8102B equipment, designed for Windscale, uses four 5 in. dia. × 4 in. thick NaI(Tl) crystals, thereby permitting scintillation spectrometry with high counting efficiency in an arrangement where the count rate is independent of localization. In addition, a 3 in. dia. × 5 in. thick crystal with lead collimator is used to give localization.

The overall resolution of the four



The NE8102B body monitor, with five large NaI(Tl) scintillators, gives high counting efficiency

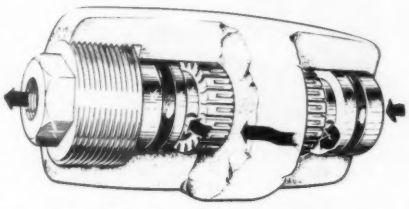
large head units, expressed as the full width at half height of the 0·661 MeV Cs^{137} gamma ray photopeak, is approximately 10%. The individual resolution of these units is in the range 8·5–10%.

★ No 208

FLUID FILTERS

One micron adjustments

I.V. Pressure Controllers have introduced an adjustable filter to cater for the present trend towards smaller particle sizes. A graduated scale on the end of the filter housing indicates the various settings which may be selected, in increments of one micron. 100% cut-off can be achieved with any particle size since



The new IVP controller adjustable filter can be completely exposed for cleaning without breaking the pipeline

the filtration gap can be diminished at will either to meet changing conditions of flow, or to attain greater cut-off efficiency.

The filter element is in the form of a conical male plug arranged to fit within a similarly tapered female housing. Only half of the longitudinal grooves are accessible to the fluid entering the filter and to escape it must pass, via the filtration gap, into the adjacent groove where the filter particles are retained. For adjusting the filtration gap, the housing is rotated round the element.

Standard models range from 6 to 11 microns for pipe size from ¼ in. to 1 in. at working pressures of 4500 lb/in².

★ No 209

CONTINUOUS LEVEL INDICATOR

capacitance operated

The new level indicator, the *Levelog*, designed by Thomas Industrial Automation for the continuous measurement of almost any material stored or contained in silos, tanks, hoppers and other containers, is capacitance operated.

Basically, the equipment consists of a control unit, which houses the necessary electronic equipment and a stabilized power unit for ensuring stable working under varying mains conditions; an electrode system, which can be of the rigid variety for small vessels, and of the flexible variety when the depth of the container is in excess of 6 ft and up to 60 ft in length; and, the main indicating instrument which is basically a d.c. milliameter for local or remote indication. The incremental change of capacitance caused by the material rising or falling in the container is used to operate an indicating instrument which may be calibrated in gallons or tons, or whatever unit of measurement is applicable.

The built-in calibrating instrument, which has a scale length of 2½ in., can also be used as a local direct reading indicator. If necessary, it can be calibrated similarly to the main indicator and, by using specially designed electrode systems and by special positioning of these electrodes in the containers, good accuracies and near linear scales can be achieved.

★ No 210

SCINTILLATION COUNTER

surgical application

A scintillation detector set, the DS8-1, has been specifically designed by Nuclear-Chicago for surgical applications. The detector housing contains a 10-stage, cæsium-antimony dynode, a photomultiplier tube with ¾ in. flat-end window and a transistorized preamplifier. A miniature switch allows a circuit change for spectrometer use, or for ratemeter or scaler use.

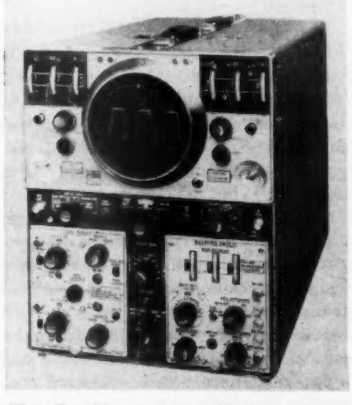
The surgical set includes three beta-gamma sensitive needle probes, the smallest 2 mm dia. × 10 cm long, the largest 6 mm × 15 cm; and a manual scanning probe, 6 mm dia. × 2·5 cm long, designed for external surface scanning. Each needle probe contains a thallium-activated cæsium iodide crystal and they are sensitive only at the ends. The manual scanner uses a large sodium iodide crystal. The detector can be used with any standard scaler, ratemeter, or gamma-ray spectrometer.

★ No 211

OSCILLOSCOPE

direct digital reading

The new type 425 Oscilloscope, manufactured by Du Mont and marketed by Leland, is a high frequency instrument for use from d.c. to 60 megacycles (down to 3 dB at 35 Mc), designed round an entirely new Du Mont tube which operates with 12,000 volts acceleration



The Du Mont 425 oscilloscope incorporates a direct digital reading system for amplitude and time measurements

potential giving very high sensitivity, high light output and high resolution on its 10 × 5 cm display area.

A variety of plug-in modular units are available which enable the range and performance of the oscilloscope to be varied and extended in a number of ways, and it is constructed in five replaceable units. A numerical read-out system eliminates the need for the interpolation and mathematical conversion of visual signals. In addition, the instrument may be connected directly to punched-card equipment for recording and analysis. Normal power requirements are 1000 watts at 60 c/s 115 volts, but it is also available for 48–450 cycle sources.

★ No 212

TEMPERATURE CONTROL

trip and warning amplifier

Elliott Nucleonics have developed a warning system which is provided with a d.c. amplifier operating from d.c. inputs, such as thermocouples. The unit is transistorized and a complete trip unit comprises a trip amplifier and transistor power supply, each plugged into a single mounting frame. The mounting frame houses the trip setting potentiometer, alarm lamps, relays, test jack socket and meter indicating margin from trip set point.

A pre-trip warning can also be incorporated with a panel control to make a setting at a fixed level below the trip level. Indication of the trip is by a red lamp, and of the warning, by an amber lamp. In both cases a normally energized relay will be released. A trip level may be set to an accuracy of 0·1% with digital indication of setting. Six standard input current and input voltage ranges varying from 0–10 μA to 0–30 mA and 0–10 mV to 0–150 mV are provided and the range may be changed by plug-in range card.

★ No 213

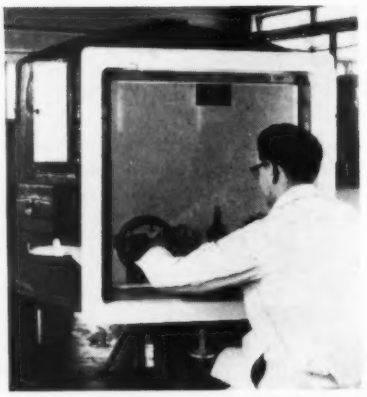
ROTARY GLOVE BOX

glass fibre moulded

The new rotary glove box, designed by Seton Creaghe for high corrosion resistance and minimum leakage rate, is made from polyester resin glass fibre laminate.

Fitted at the centre of the dome-shaped roof is a 6 in. explosion port that is sealed by a rubber ball which lifts when pressurized above 1 in. W.G. A bag ring enables the released gases to be evacuated via the extract system and a standard Vokes extract filter, fitted with a quick-release clamp for easy one-handed operation, is contained inside the glove box.

The glass fibre box is mounted on a tubular stand fitted with castors incorporating braking facilities, and variations of up to 6 in. can be made in height.



Use of glass fibre makes this new glove box easy to move and decontaminate

The glass fibre turntable, which is also supported on castors, has been arranged to lift clear of the floor of the main box for easy decontamination purposes and can be locked in any position by a foot-brake.

The dimensions of the Secray Mark III glove box are: overall height 6 ft 8 in., diameter 4 ft 3 in., height of box 3 ft 8 in. Weight is 600 lb.

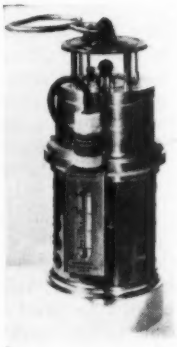
★ No 214

CO_2 DETECTION

automatic alarm

An instrument, designed for detecting and measuring the percentage of CO_2, and giving an alarm when the percentage reaches a pre-determined amount, has been developed by International Gas Detectors.

Any CO_2 in the atmosphere is absorbed by a carton of soda lime in the porous pot, thereby producing a vacuum equal to the percentage of CO_2 surrounding the porous pot. This percentage is measured directly on the gauge and can be read at any time.



The Ringrose gas detector automatically signals the presence of CO_2 in the atmosphere

In addition, access is made from the porous pot to an aneroid diaphragm, contacts on which can be set to operate through a dry battery and illuminate a red bulb when the percentage of CO_2 reaches a pre-determined amount, thus giving an automatic alarm of the presence of CO_2 in the atmosphere. The instrument can be used either as portable, or in a fixed position.

★ No 215

DATA PRINT-OUT

automatic recycling

A new scaler and crystal-controlled timer combination has been designed by Hamner Electronics which permits data print-out in many flexible modes of operation. It has a preset count of 15 settings from 10 to 500,000 counts, and a preset time of 15 settings from 1 to 50,000 seconds. For combined preset time and count, any of the time or count settings may be used simultaneously with the system stopping when the first preset event occurs.

Hamner's N-803 timer and N-276 scaler can be used in combination or separately

Both scaler and timer provide 'staircase' outputs, for operation of a digital printer. A binary coded decimal (1-2-2-4) output can also be provided for operation of data handling equipment. The system will recycle automatically, if desired, following occurrence of a pre-set event and data print-out, in which case, print-out can be cumulative or cyclical. Both print-out and automatic recycling can be used in any mode of operation.

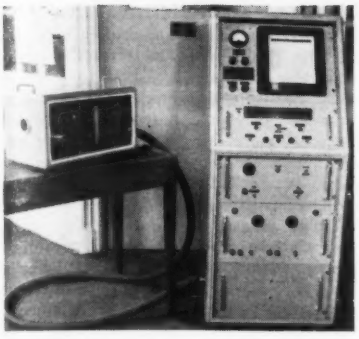
★ No 216

BERYLLIUM MONITOR

automatic recording

The '4W' Beryllium Monitor, designed by the UKAEA for the detection of beryllium aerosols, is now being manufactured by Winston. It visually records on a graph, every sixty seconds, the beryllium content of a fresh sample of the atmosphere in which the instrument is present. It gives quantitative results over the range of 1 to 75 millionths of a gram per cubic metre, irrespective of the particle size or chemical composition of the beryllium atmospheric dust. Its accuracy is now ± 15% for beryllium metal, and ± 30% for beryllium compounds and alloys.

The air to be sampled is drawn through



The UKAEA beryllium monitor is fully automatic and operates on a predetermined cycle

a specially designed chamber in which any beryllium present is optically excited as it passes through a triggered alternating current arc. The triggered a.c. arc has a long time constant and a wide plasma cross-section which results in efficient excitation of particulate beryllium metal and its intermediates. The ultra violet radiations from the excited beryllium are then resolved into their components by means of a spectrograph, which is specially designed to have a high dispersive power.

The intensity of the beryllium doublet at 3130A, which is proportional to the concentration of beryllium present in the air sample, is measured photo-electrically. The ratio of the intensity of this doublet to the intensity of the adjacent background is then recorded on a chart as beryllium line background.

Automatic calibration is achieved by the use of a simple condensed spark discharge between a beryllium-copper electrode and a copper counter electrode, producing an aerosol containing a uniform concentration of beryllium at a constant rate, the air for this being drawn through special filters.

★ No 217

ARC WELDING METER

wide current variation

A new welding meter from English Electric enables electrical conditions in a welding arc to be measured, but it can also be applied to costing, calculating efficiency, developing electrodes and improving production techniques. The unit consists of a watthour meter, ammeter, voltmeter and protective relay, all housed in a case (16½ in. × 5¾ in. × 6½ in.), suitable for switchboard or wall mounting. The user can see at a glance the arc voltage and current and the total energy being consumed.

The watthour meter pointer moves over a 4 in. diameter scale, one revolution of the pointer being equivalent to 100 watthours at 100/5 amps. For other ratios a multiplying constant must be used. The pointer can be re-set to zero after each welding operation by depressing the knob in the meter glass and turning anticlockwise. The total watthours are shown on the meter register.

The ammeter and voltmeter are of the 4 in. square moving iron pattern, and zero adjusters are accessible through cover plates in the meter window. The voltmeter is scaled 0–120 volts and is marked 1 volt per division between 20 and 45 volts, the normal arc voltage range. The ammeter is scaled 0 to 120 amps and reading direct for a current transformer ratio of 100/5 amps. For other ratios a constant must be used. The relay ensures against overcurrent in the event of the meter being used with an incorrect current transformer ratio.

★ No 218

IN BRIEF

• **Reciprocating compressors.** The new range of vertical reciprocating compressors being produced by Bryan Donkin include a 6 in. stroke machine, supplied as single, two or three crank, and an 8 in. and 12 in. stroke compressor made with either two or three cranks. The maximum flow of free air obtainable with the 12 in. type at discharge pressure of 100 lb/in² is about 3600 ft³/min.

★ No 219

• **Frequency measurements.** A new meter, WIK, marketed by Aveley, measures frequencies up to 1000 Mc/s, permits frequency variations to be observed by pointer and provides for recording frequency drift. A pure sine wave output at all frequencies up to 30 Mc/s is given.

★ No 220

• **Transistor choppers.** For use with thermocouples, Smiths Aviation have developed a transistor technique with a drift rate of better than 1·5 μv/°C without selection from a batch or setting-up.

★ No 221

• **Valve testing.** A new universal valve test set VT10 from APT Electronics incorporates stabilized power supplies, meters for accurate measurement of static characteristics, and an a.c. bridge that enables direct readings of mutual conductance to be made.

★ No 222

• **Field plotting.** A new resistance analogue from Servomex uses a special type of resistance paper and has silver electrodes painted on it. It is a cheap two-dimensional version of the electrolytic tank and allows the plotter to draw the map of potential and flow lines with convenience.

★ No 223

• **Scintillators.** Pilot Chemicals are marketing pilot film scintillators ranging in thickness from ¼ to 5 mils and in sheets of about 11 in. dia. They can be used as fast detectors or as image intensifiers in such fields as autoradiography.

★ No 224

• **Seam welding.** The Circomatic automatic girth seam-welder introduced by Rockweld can be operated by two welders and a storage tank of some 140 ft dia. can be completed in 30 man-hours. The machine consists of two enclosed platforms hung from a top carrier, both of which are fitted with pivoted adjustable motor operated arms. Each arm carries an operated controlled automatic welding head and a slag-supporting device.

★ No 225

• **Cable jointing.** Bakelite have developed a series of epoxide and polyester resins that possess good adhesion to most surfaces and can be used for cable jointing. Simple moulds are quite adequate and obviate the use of costly metal joint boxes.

★ No 226

• **Porous filters.** Vokes' latest filter media Poroloy are available in stainless steel, nickel-chrome and Inconel nickel and the filter inserts can withstand differential pressures of over 3500 lb/in². and operating temperatures ranging from − 350°F to above 500°F. Nominal pore size ratings vary from 2 to 1000 microns.

★ No 227

• **Mechanical seals.** The Sectaflex split mechanical seal from Flexibox enables quick replacement of worn parts without stripping down the shaft. Leakage rate is a few c.c. per hour and the seal can be used at pressures up to 100 lb/in²g and temperatures up to 300°F.

★ No 228

• **Speed measurement.** Dawes have introduced a portable transistor stroboscope that weighs only 4 lb and has an accuracy of ± 2%. Two ranges are provided that cover 600 to 15,000 flashes/minute.

★ No 229

• **Magnetic recorder.** Gresham's A/25/RP multitrack head is designed for use with either magnetic tape or drum and may be used in-contact or out-of-contact with the recording medium. For analogue work, it is suitable for direct recording using a.c. bias, frequency modulations, amplitude modulation, or pulse-width modulation. For digital recording, the two windings per track are convenient.

★ No 230

STUDENTS' NOTEBOOK

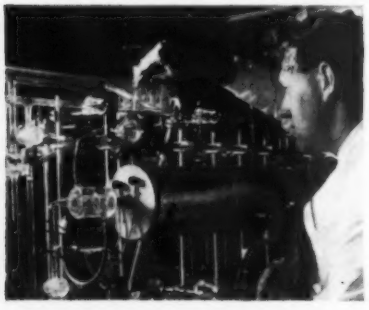
GROUNDWORK—Careers

What opportunities are there in the nuclear field for the young scientist?—2

In the first of this series on careers for scientists, we gave guidance to the young physicist, and a substantial part of what was said is common to other science disciplines, particularly that concerning educational opportunities for apprentices and postgraduate training.

The Chemist. The number of scientists in this field, some 26,000, represent about 75% of the total employed in this country, two thirds of whom are in industry and about half of these are engaged on research and development. The chemical industry is constantly meeting new challenges and a diversity of openings are available, more than in any of the other scientific fields.

With the bewildering number of avenues open to the young chemist, the question arises as to what appeal there is in the nuclear industry. Apart from the possible glamour that surrounds it, the industry is predominantly a young man's one and it offers extensive scope for research in most of the branches—in analytical chemistry, where the amounts of substances for determination become smaller and smaller and accuracy and speed of analysis increases; in physical chemistry, where the effects of temperature, pressure, and rates of reaction on chemical processes are important in ultimate plant construction; in organic chemistry, for the study and production of ceramics, the extraction of the less common metals, and the production of artificially produced radioactive elements; and in biochemistry, where there is an increasing interest in radiation effects on living organisms and in radioisotope tracer techniques.



Opportunities in the radiochemical field are increasing, particularly in the UKAEA, where research on radioisotopes, and their production and distribution, is rapidly extending. This photo shows a chemist at the Radiochemical Centre, Amersham, purifying tritium, one of many other difficult chemical operations

Openings, therefore exist for all kinds of chemically qualified persons. For the boy and girl holding the General Certificate of Education at Ordinary level, preferably in mathematics, a science and English, there are opportunities for laboratory technicians and assistants. Facilities usually exist for courses of study leading to membership of the Institute of Science Technology, to the Intermediate qualification of the City and Guilds of London Institute, and to the National Certificates where a more academic qualification is required. Part-time study for a degree, of course, is extremely difficult.

Students who already have a degree or diploma are strongly recommended to seek full membership of the Royal Institute of Chemistry and enquire about qualification exemptions.

The Chemical Engineer. The scope of the chemical engineer has widened over the last few years and, whilst the mechanical engineer still predominates to a large extent in the nuclear industry, the importance of more specialized knowledge in applied chemistry is being recognized. Problems of heat transfer, fluid flow, mass movement, and the like, are in this field.

The demand for this knowledge is, of course, greatest from the UK Atomic Energy Authority, and it could increase from industry with the development of reactor systems that are more representative of chemical process plants; these include the organic moderated reactor and the homogeneous fluid reactors. Reactor technology as a whole, however, requires the particular skills and experience of the chemical engineer, not only for providing the special materials of construction but also for their treatment and disposal after irradiation.

There are opportunities for those inclined towards research and development, but there is also ample scope for a career in design and operation. The graduate can find a great range of work from fuel element design to whole reactor technology. In the study of coolant behaviour, fuel combustion and the like, the chemical engineer, who is trained to think in terms of very rigid specifications, is essential. This is particularly so now with the development of reactors to operate at higher temperatures.

To the chemical engineer, these many problems of design, appraisal and economics present a challenge from a young industry. The graduate is recommended not to specialize in too narrow a field, his broader training and experience will be of greater value to him and his employer. In choosing his first job, he is urged to first examine carefully the facilities offered by his potential employer, both for higher training and for practical experience. He should not allow himself to be directed to work ending in a 'culde-sac'. It is often the case, however, that once employed, either in the Authority or by industry, the opportunity for broad training is not so widely available as one could wish. It is on this point that the graduate is asked to consider very carefully the possibility of taking one of the postgraduate courses on nuclear engineering that are being run in London, Manchester, Birmingham and Glasgow, before seeking a post. The syllabus is extremely comprehensive and there is ample scope for practical work and visits to important nuclear establishments. Finally, the chemical engineer is strongly advised to consider membership of the Institution of Chemical Engineers.

FILMS

• A world catalogue of films on atomic energy is being compiled; some 400 are believed to exist but no comprehensive information is yet available. Organizations, possessing this information, are asked to send details to: Mr. A. N. Vorontzoff, 10 rue Mademoiselle, Paris 15.

• A new colour, sound film sponsored by The English Electric, Babcock and Wilcox, Taylor Woodrow Atomic Power Group shows the first two years' work on the Hinkley Point 500 MW station. Available in 35 mm or 16 mm, it runs for 29 minutes and can be obtained on free loan.

NEWSBRIEFS

• For research into the behaviour of materials at very low temperatures, Oxford University is to have a new cryomagnetics laboratory. A grant of £25,000 towards its cost has been made by Mullard Ltd.

• Scholarships, tenable for three years and worth some £400 p.a., have been awarded to 18 boys by the Civil Engineering Scholarship Trust.

• Thirty professors of electrical engineering attended a Summer School organized by AEI (Rugby) Ltd.

• Griffin and George have introduced an electronics constructional kit for student experiments on fundamental principles of electronics—mains supply is not required.

• Some 250 delegates, 100 from overseas, attended a recent symposium on nuclear reactor containment buildings and pressure vessels organized by the Royal College of Science and Technology, Glasgow (see report on p 79).

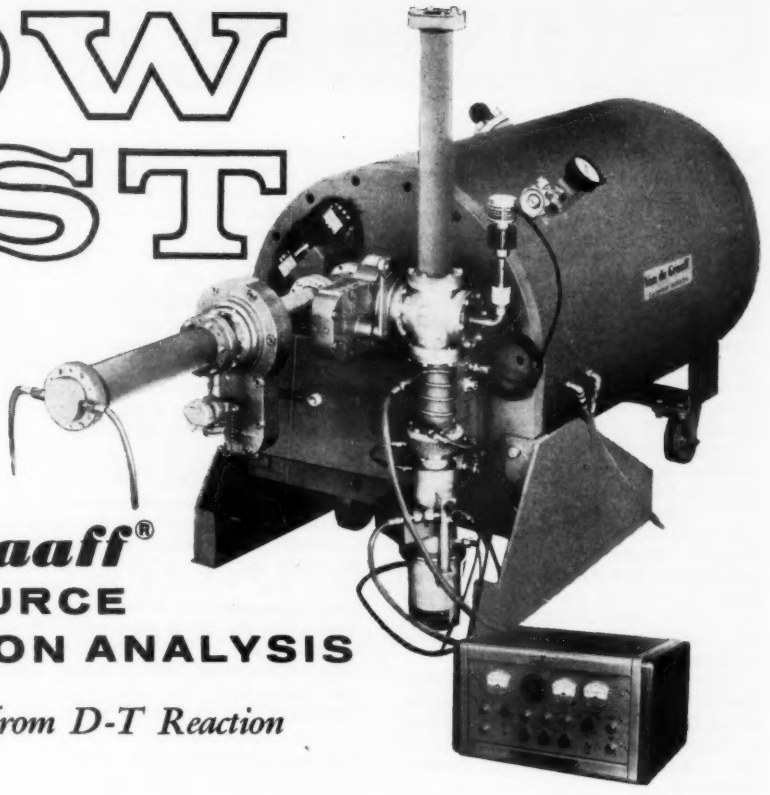
• The new technical college to be erected in Paisley is to include nuclear physics and radiation laboratories.

UK COURSES

Nottingham University Measurement for Automatic Control. Residential course, September 12–16. Fee: 20 guineas (including accommodation).

Chelsea College of Science and Technology, London Nuclear Physics. 1 year M.Sc. course commencing September. Fee: £30.

LOW COST



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BUSINESS NEWS

GEC-APC REAGREEMENT Several recent mergers include that between *Atomic Power Constructions Limited* and the *GEC - Simon - Carves Atomic Energy Group*. Their agreement on collaborating in the design and building of nuclear power stations follows the breakdown of earlier talks (see *Worldview*, April and this issue). This combination reduces the number of consortia from the original five to three; the other two are the *Nuclear Power Group* and the *English Electric, Babcock & Wilcox, Taylor Woodrow* group.

On a different plane is the announcement by the *Cambridge Instrument Co. Ltd.* that they have bid for the ordinary share capital of *Electronic Instruments Ltd., Richmond*. This merger has been mutually sought after and, in recommending the bid to shareholders, Electronic Instruments say that the merger will enable both firms to co-ordinate their resources and create a more powerful organization.

Mancuna Engineering Ltd. of Manchester has purchased *Sturtevant Engineering Co. Ltd.* This acquisition will add to Sturtevant's productive capacity and also extend its range of gas cleaning equipment.

Meanwhile, Simon-Carves are in the process of joining up with their neighbour, *Henry Simon (Holdings) Ltd.* The various resolutions for the merger of these two companies have been passed. At the same time, Mr. R. B. Potter, chairman of Simon-Carves, added to his annual statement by correcting the implication that the GEC-Simon-Carves group would incur a loss of over £2 million on the Hunterston contract. Speaking for his company only, Mr. Potter said: 'There is no evidence that substantial losses will, in fact, be incurred.'

ORDER FOR BURST SLUG EQUIPMENT *Plessey Nucleonics Limited* are to supply auxiliary burst slug detection equipment for the Advanced Gas-Cooled Reactor at Windscale. This order follows that announced at the end of last year when Plessey received a contract to supply the main burst slug detection equipment for the same reactor. The latest equipment will be incorporated in the reactor's loop facilities (see *Progress in Industry*, in this issue). The company is also in the process of developing portable and installed detectors for the test loops and refuelling machine.

TI SALES SUCCESS Orders are being received at the rate of one a month—£200,000 a year—from home and overseas customers for the X-ray scanning microanalyser developed by the *Tube Investments Research Laboratories* in collaboration with the *Cavendish Laboratory* at Cambridge. Deliveries have begun and three instruments will be delivered to the United States this year. The microanalyser provides for qualitative and quantitative metallurgical analysis.

CEGB BUYS PORTABLE MONITORS An order for 86 radiation monitors has been placed with *Ekco Electronics* by the *Central Electricity Generating Board*. They are all portable, battery-operated instruments, for use at the Berkeley, Bradwell and Hinkley Point power stations.

RELAYS FOR HINKLEY In addition to becoming sole concessionnaires in the UK for Fido (fallout intensity detection oscillator), manufactured by *Control for Radiation Inc.* of the USA, *L. E. Simmonds Ltd.* of Harrow, have secured orders for over 10,000 Post Office type 3000 relays for use at the Hinkley Point nuclear power station. Trial orders for Fido, a miniature, self-contained dose-rate alarm, have also been received by Simmonds from the UKAEA.

TRAWSFYNYDD ORDERS *Atomic Power Construction Ltd.* are to order two main reactor rod control boards worth £50,000 for the Trawsfynydd power station from *Lancashire Dynamo Nevelin*, a company in the *Metal Industries Group*. The boards will control the power supplies that lower and raise graphite rods into the reactors and will be about 100 ft long. Delivery is to be in 1962. Also scheduled for Trawsfynydd are six Allen-Stoeckicht epicyclic gear units for motor driven horizontal circulating water pumps. They were ordered by *Drysdale & Company Ltd.* of Glasgow from *W. H. Allen Sons & Company Ltd.*

CHANGES OF ADDRESS *L. G. Mouchel and Partners*, consulting civil engineers, have moved from Victoria Street to Southbank House, Black Prince Road, Albert Embankment, SE11.

Royce Electric Furnaces Ltd. are now situated at Albert Drive, Sheerwater, Woking, Surrey.

OVERSEAS

RADIATION WARNING SYSTEM An automatic radioactivity alarm system has been developed by *Japan's Atomic Energy Research Institute* and is to be installed in and around the research centre at Tokai-Mura. The system, which is expected to be operating this month, gives atmospheric readings of radioactivity through teletyped messages printed in black or red. Any warning will be automatically printed in red.

AEI's AMERICAN SALES LINK A move to increase the marketing of *Associated Electrical Industries Limited's* nuclear laboratory instruments in the US has come with the recent announcement by the Picker *X-Ray Corporation* that it is now AEI's US agent in that field.

GERMAN MARINE REACTOR MOVES Two German firms have decided to co-ordinate their efforts to develop a gas cooled marine reactor. They are *Deutsche Babcock & Wilcox-Dampfkessel Werke AG (Oberhausen) and Blom & Voss (Hamburg)*. The two firms are to undertake experimental work over a period of two years (see *Nuclear Merchant Ship Survey* in this issue).

Captain A. de Groote, commander of the N.S. 'Savannah', visits the British Shipbuilding stand at the British Exhibition, New York, where the Fairfield Shipbuilding and Engineering Company Ltd's model of a marine reactor system aroused his interest. With him are Sir James Milne, chairman of the Council of the British Shipbuilding Research Association, Vice-Admiral E. W. Langley-Cook, J. C. Macfarlane of Fairfield, and R. B. Shepheard, director, the Shipbuilding Conference

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Diary

25–29 JULY
13th International Congress on *Occupational Health*, New York. Enquiries, Dr. R. E. Eckardt, P.O. Box 45, Linden, N.J., USA

25 JULY–6 AUGUST
12th General Assembly, International Union of Geodesy and Geophysics, Helsinki, Finland.

31 JULY–5 AUGUST
Third International *Photobiological Congress*, Copenhagen, Denmark. Enquiries, Dr. A. Hollaender, Oak Ridge National Laboratory, Tennessee, USA

3–6 AUGUST
Rarefied Gas Dynamics, Second International Symposium, University of California, Berkeley, California, USA

8–12 AUGUST
IAEA *Effects of Ionizing Radiation* on Seeds and its Significance on Crop Improvement Karlsruhe, Germany

15–17 AUGUST
International Conference on *Organic Scintillation Detectors*, University of New Mexico, Chemistry Department, Albuquerque, New Mexico, USA

15–18 AUGUST
Third Australian Conference on *Radiation Biology*, Sydney, Australia. Enquiries, Dr. Peter Ilbery, Dept. of Preventive Medicine, University of Sydney

15–25 AUGUST
21st International *Geological Congress* Copenhagen, Denmark, Enquiries Theodor Sorgenfrei, c/o Mineralogisk Museum, Oster Voldgade 7, Copenhagen K

23–25 AUGUST
1960 *Cryogenic Engineering* Conference University of Colorado and National Bureau of Standards at Boulder, Colorado

24–28 AUGUST
Machine tool control systems, Institution of Production Engineers Symposium at College of Aeronautics, Cranfield

25 AUGUST—1 SEPTEMBER
Tenth International Conference on *High Energy Nuclear Physics*, International Union of Pure and Applied Physics and Commission on High Energy Physics at Rochester, New York, USA

29 AUGUST—2 SEPTEMBER
Initial effects of radiation on living cells, UNESCO symposium, USSR Academy of Sciences, Moscow
International Conference on Semiconductor Physics, Prague, Czechoslovakia. Enquiries Dr. Milos Matyas, Institute of Technological Physics, Cukrovarnicka 10, Prague 5

29 AUGUST—3 SEPTEMBER
International Conference on *Nuclear Structure* at Queen's University, Kingston, Ontario, Canada. Details, Dr. L. G. Elliott, Atomic Energy of Canada, Chalk River, Ontario

Seventh International Conference on *Low Temperature Physics*, Toronto. Details, Professor H. Hallett, Dept. of Physics, University of Toronto, Ont., Canada

Use of Radioactive Isotopes in the study of bone, International Research Symposium, New York. Details, Council for International Organizations of Medical Sciences, 6 rue Franklin, Paris 16e, France

31 AUGUST—7 SEPTEMBER
Annual meeting at Cardiff of the British Association for the Advancement of Science

31 AUGUST—11 SEPTEMBER
St. Eriks Fair, Stockholm. Capital and consumers goods, with specialist sections

1 SEPTEMBER
Rocket and Satellite Instrumentation One day symposium by the Society of Instrument Technology and the British Interplanetary Society in London

1–7 SEPTEMBER
Fifth International Congress on *Nutrition*, Washington. Details, General Secretary, 9650 Wisconsin Avenue, Washington 14, USA

5–8 SEPTEMBER
Legal and Administrative Problems of Protection in the field of peaceful applications of Atomic Energy, International Euratom Symposium, Brussels

5–9 SEPTEMBER
IAEA Conference on *medium and small power reactors*, Vienna

6–7 SEPTEMBER
Fundamental Aspects of Atomic Reactions, Symposium, Montreal. Details, Chemical Institute of Canada, 48 Rideau Street, Ottawa 2, Canada

6–8 SEPTEMBER
Nuclear and Radiochemistry Symposium, Chalk River, Canada. Details, Dr. R. H. Betts, Atomic Energy of Canada Ltd., Chalk River, Ontario, Canada

13–15 SEPTEMBER
Fifth International *Instruments and Measurements Conference*, Stockholm. Details, Tekn. Lic. Helge von Koch, Kungl. Teknska, Hopkolan, Stockholm 70

14–19 SEPTEMBER
21st National Congress of the Italian Society of *Medical Radiology and Nuclear Medicine*, Bologna, Italy

11–13 OCTOBER
Deutsches Atomforum Conference on the *Applications of Nuclear Energy*, Karlsruhe. Details, Prof. Ing. Kupfmuller, Deutsches Atomforum, Fredrichstr, 2 III, Düsseldorf, Germany

11–14 OCTOBER
Inelastic Scattering of Neutrons in Solids and Liquids, IAEA Symposium, Vienna

7 DECEMBER (provisional)
Dounreay Fast Reactor Symposium (arranged under aegis of British Nuclear Energy Conference), Institution of Mechanical Engineers, London, SW1

12–14 DECEMBER
Winter Meeting of the American Nuclear Society, including 8th Conference on Hot Laboratories and Equipment San Francisco, California

12–16 DECEMBER
Use of Radioisotopes in the Study of Endemic and Tropical Diseases, IAEA Symposium, Bangkok, Thailand

14–16 DECEMBER
1960 Annual Conference of the Atomic Industrial Forum, San Francisco, California

Industrial Literature

Machinery directory. The 1959 edition of the ' International Directory ', published by the Office for Industrial Information in Geneva, covers primarily the precision engineering trades in Switzerland, including atomic industry suppliers. Entries, which are in six languages, are indexed thoroughly. ★ No 241

Chemical plant. The British Chemical Plant Manufacturers Association have issued their 1959 edition of ' British Chemical Plant ', a comprehensive and authoritative guide to manufacturers and their products. A detailed subject index is given in English, French, German and Spanish. ★ No 242

Thermal insulation. A recent booklet from Stillite presents technical data for the estimation of heat losses and temperature gradients in insulated systems. Calculations are possible for most conditions provided that certain basic data are known. ★ No 243

** For further information on any item circle the appropriate number on the reply card facing page 138.*

Humidity control. Burnett and Lewis' latest publication covers mainly their range of fully automatic gas dehydration and humidity control equipment. ★ No 244

Heavy fans. The 4th edition of Blackman's publication no. 25 introduces the current range of heavy duty fans, blowers and exhausters. ★ No 245

Automatic brazing. The Spring issue of ' Sif-tips ' includes articles on the automatic electro-gas-air brazing of mild steel assemblies and on the salvaging of spot-welding tools. ★ No 246

Thickness testing. The use of ultrasonic gauging for thickness measurement of difficult components is described in the current issue of ' Dawe Digest '. ★ No 247

Radioactive materials. Continuing his ' Plain Man's Guide to Atomic Energy ' in the current issue of ' Fairey Review ', Mr. P. J. Duncton discusses the characteristics of radiation. ★ No 248

Industrial pipes. Stewart and Lloyds have issued a new brochure giving a great deal of useful information to engineers concerned with industrial steel pipework design. Calculations for pipe bores and thicknesses are given and, apart from the British Standard tables of pipe flanges, other tables cover the design of expansion bends, the calculation of flow resistance, friction loss and pressure drop. ★ No 249

Atom chart. A coloured version of the ' Periodical Chart of the Atom ' has recently been published by the Atomic Development Mutual Fund, Inc. of Washington. Another table of the elements, which includes all the known isotopes, has been issued by Fairey Engineering Ltd. ★ No 250

Self-lubricating bearings. A new catalogue from Pollard Bearings gives details of their range of self-lubricating ball bearing pillow blocks and bearing units, and includes dimension and load ratings tables, together with bearing selection data. ★ No 251

Non-destructive testing. ' Solus Schall News ' for this month describes the use of Statiflux powder for testing ceramics. Other articles cover ultrasonic testing of tubes less than 25 mm by the immersion method, and the detection of flaws in plate above 0·2 in. thick. ★ No 252

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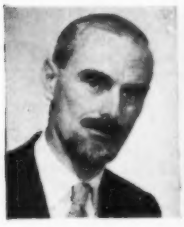
People

by John Radford

Dragon project workers will no doubt be watching with close interest the work of **Dr. Peter Fortescue** who has now been appointed chief research and development engineer of the newly organized General Atomic Europe. Peter Fortescue was deputy chief scientist at Harwell and an advocate of the High Temperature, Gas-cooled Reactor concept before he left to join General Atomic Division of General Dynamics Corporation. He is now to be in charge of a group developing a high temperature, gas-cooled power reactor in the 100 MW range, suited to the requirements of European



PETER FORTESCUE
returns to Europe

N. de BRUYNE
dream retirement

electric power generating systems. I expect that he will be passing through the UK before he takes up his appointment in the autumn of this year and that he will take the opportunity of meeting former colleagues.

I am told that **Dr. N. A. de Bruyne's** recent resignation as managing director of Ciba (ARL) Ltd., results from his wish to devote more time to research, especially to the development of scientific instruments. Dr. de Bruyne founded the company in 1934, some five years after his election as a Prize Fellow of Trinity College for research work at the Cavendish Laboratory, Cambridge. He retains a connection with the company, however, for he will remain on the board. When his resignation takes effect at the beginning of January next year, **Mr. R. F. G. Lea** and **Mr. D. A. Hubbard** will become joint managing directors with Mr. Lea as deputy chairman of the company.

The number of appointments to boards of directors in recent weeks does seem to lend encouragement to the now often quoted saying that there is 'Room at the Top.' Latest of these include that of **Mr. J. C. Nutter,** a director of Elliott Nucleonics Limited, and **Mr. R. Y. Parry,** to the board of Isotope Developments Limited. Mr. Parry, who was with Isotope Developments before Elliott's took over earlier this year, is the manager of the company's works near Aldermaston.

Three other companies have announced board changes. Sulzer Bros. (London) Ltd. tell me that **Mr. R. M. Atkinson** has retired from the position of managing director of Sulzer and of Hathorn Davey & Co. Ltd., and is appointed chairman of the board of each company. In addition, Messrs. **E. H. Stagg, G. W. Heslett** and **M. W. Zublin** have been appointed joint managing directors of each company. John Bass Limited have appointed **Mr. E. J. Granger,** a former industrial consultant, and **Mr. J. W. Reynolds,** technical sales manager of W.H.S. Radiators Ltd., to their board. Last in my list for the moment is the announcement by the recently-formed electronics firm, LCE Ltd., that the chairman of the board is to be **Lord Halsbury** of Joseph Lucas (Industries) Limited with **Mr. Jonathan H. Lasley** of Collins Radio Company of England as vice-chairman.

The pace is stepping up at the Tokai-Mura site in Japan where the British General Electric Company is building the country's first nuclear power station. The recent arrival of **Mr. K. A. Lowe,** who is to be chief resident engineer at Tokai-Mura, and of **Mr. R. D. Harvey,** deputy chief engineer (electrical and mechanical) of the GEC Company of Japan Limited, brings the British staff there to 22. Director and manager of the project is **Mr. R. J. Smith,** chief projects engineer of the GEC & Simon-Carves Atomic Energy Group. Among the others is **Mr. F. W. Evans,** chief engineer (Japan) Simon-Carves, who was deputy chief resident engineer at Hunterston.

K. A. LOWE and R. D. HARVEY
in Japan for the GEC

The new director of advertising and public relations for the US Babcock & Wilcox Company is to be 45-year-old **M. E. Ziegenhagen.** In his own sphere, Mr. Ziegenhagen is well known as an author and speaker and is at present chairman of the board of trustees of the Industrial Advertising Research Institute.

After only two years as London representative, **Mr. Bernard Wright** of John Thompson Instrument Company Ltd., has been promoted to sales manager. Before joining the company in 1958, Mr.

BERNARD
WRIGHT
rapid promotion

G. H. DOUST
Plessey
International

Wright was technical representative for Dewrance and Co. in Manchester and Birmingham. He will continue to be based at John Thompson's London office in Kingsway.

Before his appointment in November 1958 as deputy to the general manager, and now as general manager of Plessey International Limited at Ilford, **Mr. G. H. Doust** was in charge of the commercial and sales department of Plessey Chemical and Metallurgical Division in the quiet, small Northants town of Towcester. Previous to this, Mr. Doust was field sales manager of the metal finishing division of the Pyrene Company Ltd.

The success that **Mr. Antony Norman,** chairman of Electronic Instruments Ltd. had on his recent trip to the United States and Canada will, I expect, prompt trips by executives of companies in similar fields. Mr. Norman spent four weeks away from home, during which time he made cooperative research arrangements with the Milton Roy Company of Philadelphia, and visited the associate EIL concern, the Glendon Instrument Co. Ltd. in Canada. The agreement to pool research activities was, Mr. Norman states, 'so that both companies will get the benefit of each other's ideas.' The US, incidentally, is still EIL's biggest export market.

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Book Reviews

Thermodynamics applied

Available Energy and the Second Law Analysis by E. A. Bruges 1959: Butterworth Scientific Publications, London 124 pp Price 25s

This book is concerned with the Second Law of Thermodynamics, the Carnot principle, the concept of available work which thereby results, and the application of this concept to a number of common engineering problems

Chapters 1 and 2 form a brief revision of the First and Second Laws of Thermodynamics, but it is in Chapter 3 that the reader is introduced to the very heart of the book—the concept of available energy. Criticism might be offered at this point concerning the brevity of explanation in the analysis of the General Case. Irreversible processes are considered in Chapter 4 and the loss of available energy caused by irreversibility is determined.

The remainder of the book is devoted to applying the principle of available energy to fluid mixtures, heat exchangers, compressors, gas flow, refrigeration, power plant, chemical changes, steam generators and internal combustion engines. Chapter 6 on the performance of a simplified Calder Hall type heat exchanger is of particular interest in demonstrating the value of the 'energy transfer ratio' as a criterion of heat exchanger performance.

In general, this is a well presented book, although not without certain minor faults such as changing from physical to numerical equations without reference to the units used, in Chapter 4. The text is not complete in itself in that, as indeed is stated by the author, it presupposes some knowledge of applied thermodynamics. However, as an addition to basic texts, such as those by Keenan and Schmidt, it should prove to be of value to both students and teachers of applied thermodynamics.

W. Redpath

High pressure plant

Design and Construction of High Pressure Chemical Plant by Harold Tongue. 1959: Chapman and Hall, London 250 pp Price 84s

The scope of this book is less broad than its title suggests as it is mainly concerned with the *mechanical* design and construction of components of high pressure chemical plant. Such topics as heat transfer and fluid flow are not discussed, and descriptions of the internal arrangement of chemical reactors, heat exchangers and air liquefaction equipment are brief. The first half contains an account of the design and fabrication of cylindrical pressure vessels and of methods of pressure measurement, together with two chapters containing valuable information on the selection of materials for high- and low-temperature service. The description of design codes and statutory requirements for cylinders would have been improved by more reference to continental practice, and by a critical review of the varying national standards for allowable stresses and weld efficiencies. The section on thick-walled tubes is well illustrated and informative, with numerous references to original papers, though these extend only to 1956 and do not include the long article in *Chemical Engineering Practice* by Bett and Newitt.

In the later chapters there are many diagrams and photographs of commercially-available gas compressors, pumps and autoclaves, and of ancillary equipment. Not all this material is well chosen to illustrate fundamental principles of design. An account of ICI's interesting reciprocating-cylinder compressor might have been included, and the scattered material on self-sealing gaskets could have been assembled into a comparative discussion of the various types. However as a guide to current practice, and to currently-available equipment, this book will be found extremely useful by anyone concerned with high pressure plant. It is well produced and, considering the number of illustrations, is reasonably priced.

K. E. Weale

Progress in Russia

Atomic Energy in the Soviet Union, by A. Kramish Stanford University Press, California; Oxford University Press, London 1960 224 pp Price 27s 6d

In the summer of 1941, the German invasion caused the Russians to divert their nuclear physicists at once to other work directly concerning the war at the very time when Britain and the USA were deciding to intensify their efforts in the hope of developing an atomic bomb. Mr Kramish produces the evidence for this statement, and examines the reasons for the Russian action. His material is drawn from a thorough study of Soviet journals and newspapers originally undertaken for the US Air Force. He gives his sources and derives his conclusions by careful and convincing argument. In the same way, in the central part of the book, the course of events during the war and up to the explosion of the Soviet atomic and hydrogen bombs is deduced. Work was apparently resumed on a very small scale in 1943, probably stimulated by knowledge that the chain reaction had been achieved in the Chicago pile in December 1942. The first Soviet reactor probably did not operate until early 1947, in which case the development from their first chain reaction to their first atomic explosion in September 1949 was about as quick as that in the US-British-Canadian war-time project. The discussion of probable Soviet policy and motives during this period is plausible and fascinating.

The latter part of the book summarizing Soviet progress in the peaceful uses of atomic energy is rather less satisfactory. Successive chapters deal with explosions for civil engineering purposes, power stations, ship propulsion, isotopes, raw materials, accelerators and thermonuclear work but the treatment is descriptive and excessively non-technical. A more critical review with a line of argument to follow, would have been more interesting even to the non-technical reader. However, these chapters contain a great deal of useful factual information, particularly about the institutions and the leading scientists, which can be found with the help of the good index.

J. A. V. Willis

New Books

● *Nuclear Ship Propulsion* by H. F. Crouch Cornell Maritime Press, Cambridge (Maryland); Putnam, London 1960 386 pp Price 87s 6d ★ 262

● *Chemical Engineering Materials,* 2nd edition by F. Rumford Constable, London 1960 384 pp Price 62s 6d ★ 263

● *Nuclear Physics and Atomic Energy:* terms in English, German, French and Russian by G. J. Béné and others Elzevier, Amsterdam 1960 213 pp Price 30s ★ 264

● *Basic Theorems in Matrix Theory* by M. Marcus (National Bureau of Standards Mathematical Series 57) US Government Printing Office, Washington 1960 27 pp Price 15 cents ★ 265

● *3rd Metallurgy Symposium on Corrosion,* Saclay 1959 North Holland Publishing Co., Amsterdam 1960 240 pp Price 72s ★ 266

● *Radioisotope Laboratory Techniques* by R. A. Faires and B. H. Parks Newnes, London 1960 244 pp Price 25s ★ 267

● *Symposium of Plasma Dynamics* edited by F. H. Clauser and others Pergamon Press, London; Addison-Wesley, Reading (Mass.) 1960 369 pp Price 84s ★ 268

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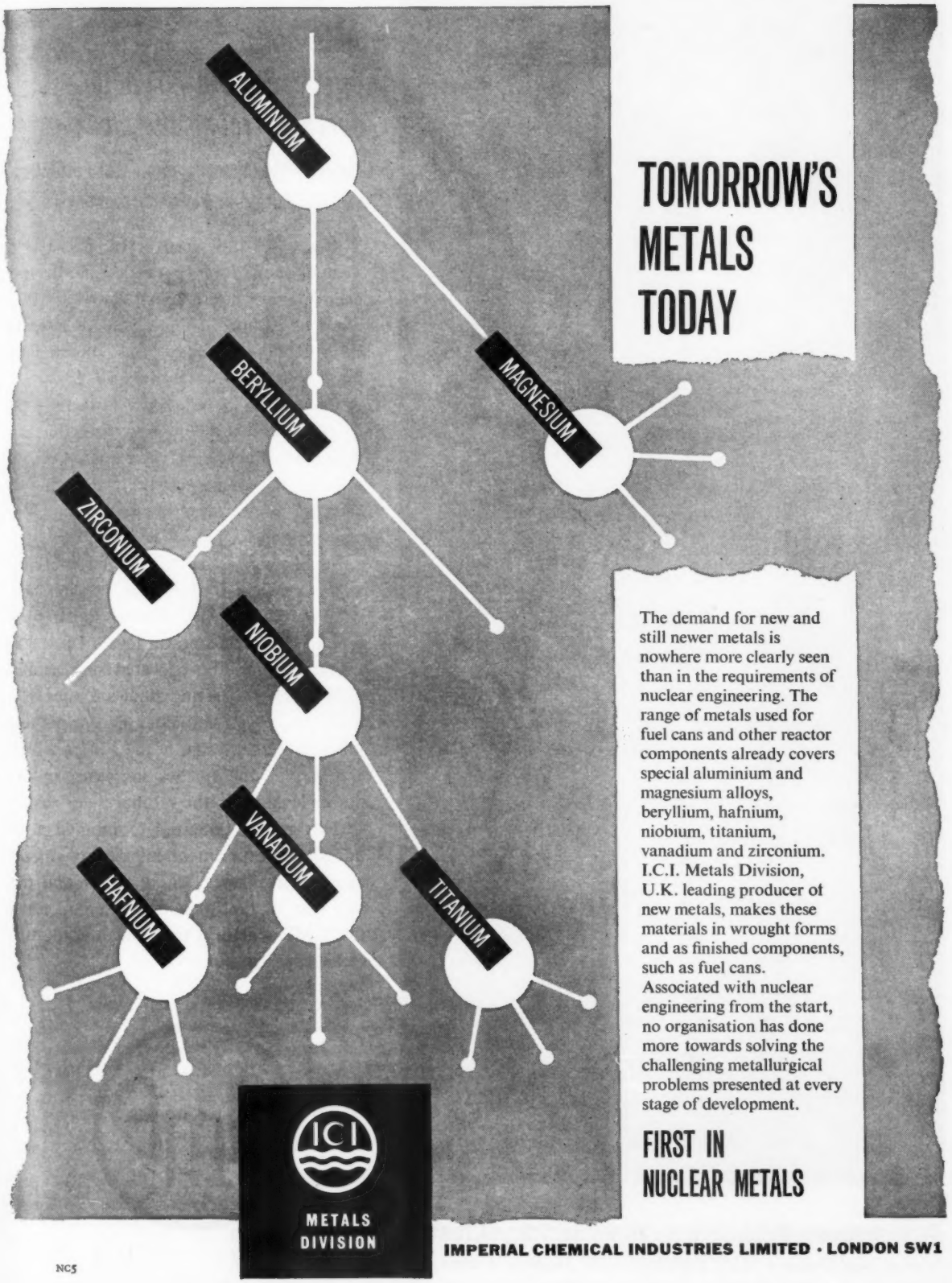

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The demand for new and still newer metals is nowhere more clearly seen than in the requirements of nuclear engineering. The range of metals used for fuel cans and other reactor components already covers special aluminium and magnesium alloys, beryllium, hafnium, niobium, titanium, vanadium and zirconium. I.C.I. Metals Division, U.K. leading producer of new metals, makes these materials in wrought forms and as finished components, such as fuel cans. Associated with nuclear engineering from the start, no organisation has done more towards solving the challenging metallurgical problems presented at every stage of development.

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Significantly, it has disproved the theories of some authorities in the industry who were concerned that an open pool type reactor with a power level of 5 megawatts could not be operated successfully *and safely*. Operating data on the IRL reactor, in fact, indicates no limitations inherent in the design of the system which would preclude further increases in the power level up to the *10 megawatt range*.

This power potential, combined with unequalled experimental flexibility, operational convenience, safety factor and the low cost of the open pool design, make this AMF reactor a truly outstanding nuclear research tool.

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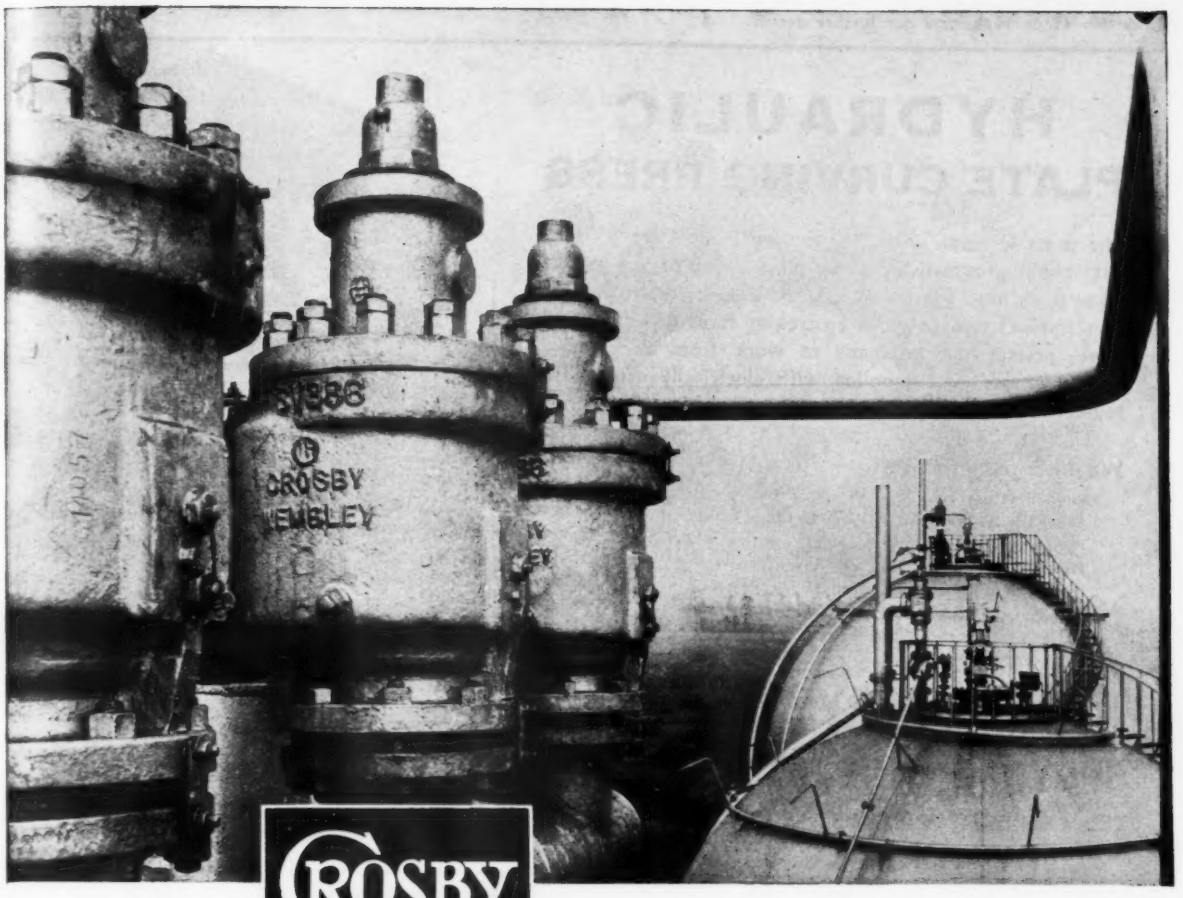

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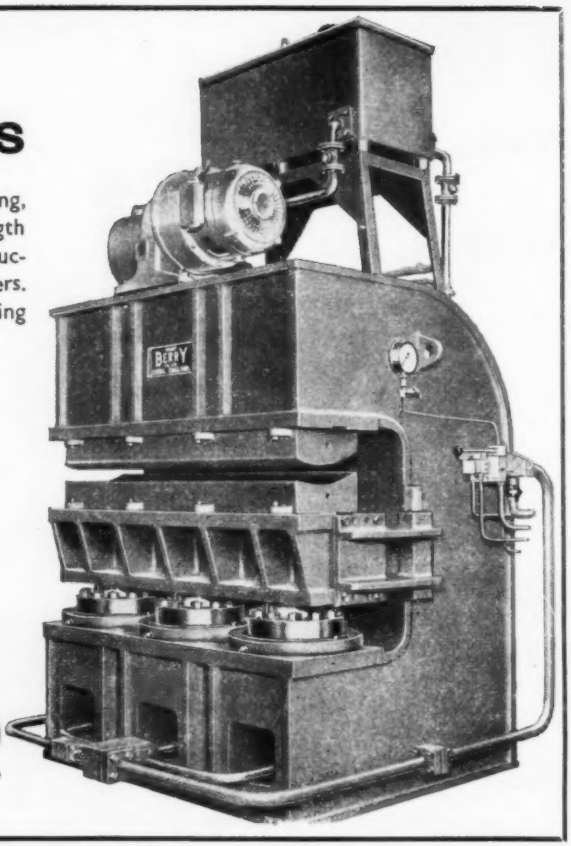

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Rotary pumps, diffusion pumps, valves, combined units—these are but a few from the very full range of equipment now being produced for the High Vacuum industry by N.G.N.....our technical services are being increasingly used to assist and advise on problems of High Vacuum. Why not make use of them—NOW.

Type HCU Pumping Plant

By means of the two hand valves used in conjunction with the baffle valve, sequence pumping may be obtained when using the Type HCU Pumping Plant which is equipped to give Rough Pumping and Fine Pumping, isolation or Air Admittance, and water relay to protect the Diffusion Pump against water supply failure. In general, the HCU is more suitable where access to the vacuum chamber is not required for production sequence cycles, and where the plant is not likely to be left running overnight without supervision.

N.G.N. FOR HIGH VACUUM
High Vacuum Specialists and Electrical Engineers

N.G.N. ELECTRICAL LIMITED
Avenue Parade, Accrington, Lancs.
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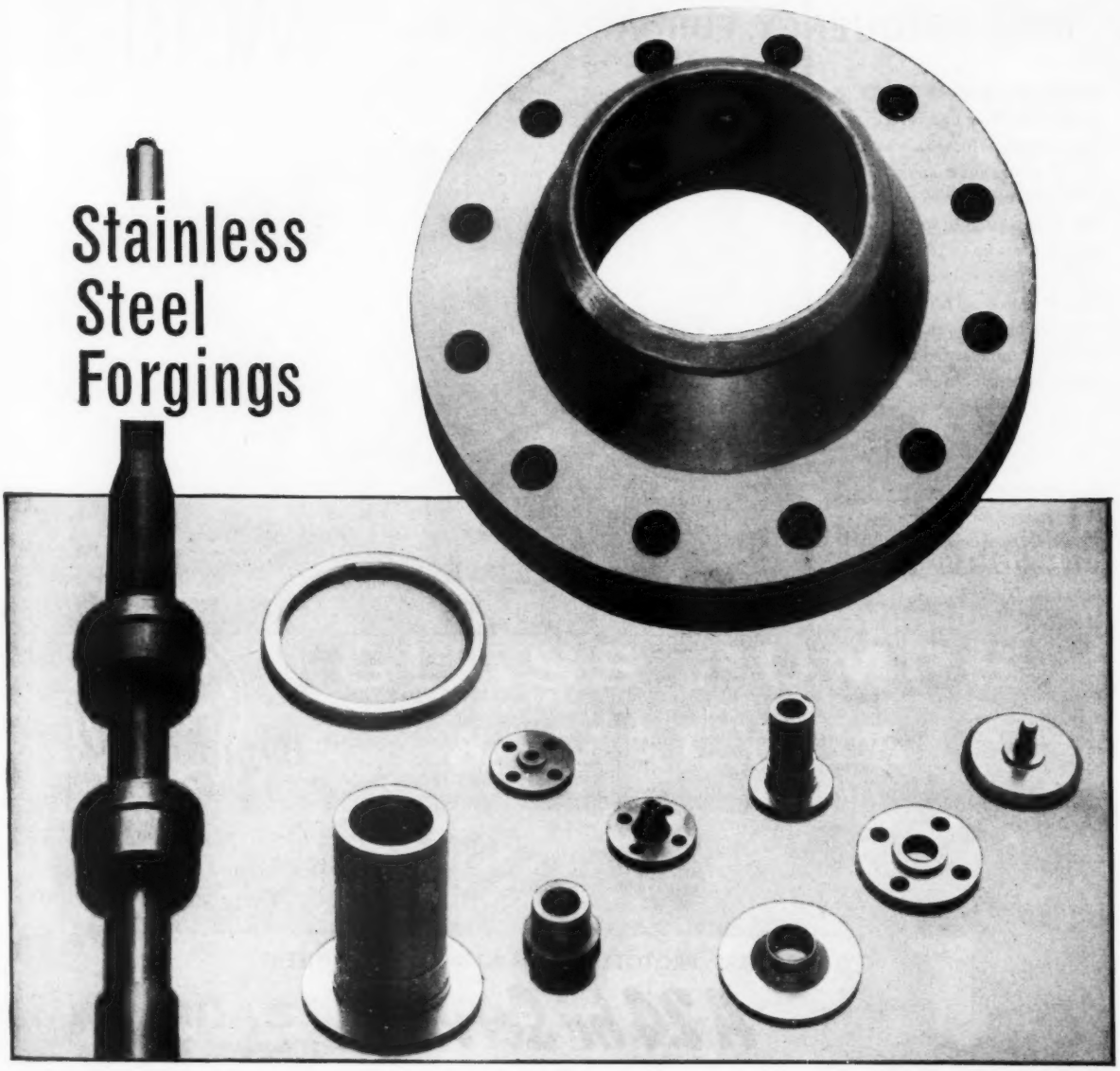
Stainless Steel Forgings



serving Atomic Energy, Aircraft and Oil industries

Manufactured to any British or U.S.A. Standard Specification
Supplied as Forgings only or Fully Machined in Modern Machine Shops on approved lists of A.I.D., A.R.B. and LLOYDS.

William Oxley & Co. Ltd.

PARKGATE STEEL WORKS · ROTHERHAM
telephone Rotherham : 5238

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HIGH FREQUENCY FURNACE *fabricated by* MUREX

The illustration shows a complete heating unit for a high frequency furnace, which can be used without any risk of contamination from carbon. The unit is designed for temperatures up to 2000°C. in vacuum. The susceptor itself is fabricated in pure Tantalum, while the inner shields are made in Tantalum and the outer shields in Molybdenum.

The unit shown was manufactured for the Research Department of Imperial Chemical Industries Limited, Metals Division.

P33

MUREX LIMITED *(Powder Metallurgy Division)* RAINHAM · ESSEX
Telephone: Rainham, Essex, 3322. Telex 28632. Telegrams: Murex, Rainham-Dagenham Telex
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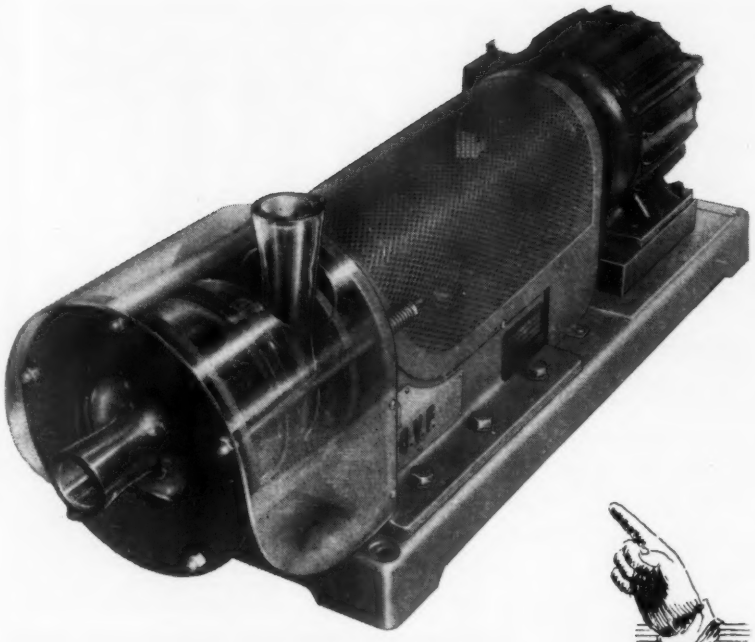
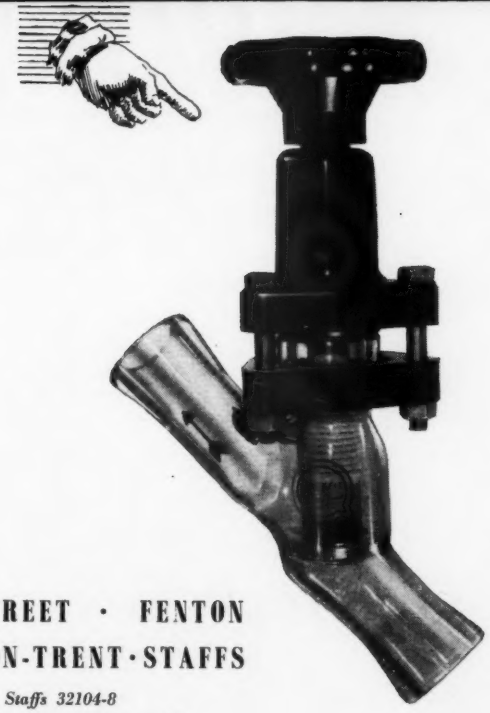


GLASS PUMP

These Q.V.F. centrifugal type Glass Pumps have effective fluon mechanical seals for successful handling of corrosive liquids; an impeller based on a vortex type inlet, and specially designed bearing chuck which holds precision ground impeller shaft.

QUICKFIT *Visible Flow*

GLASS PUMPS & VALVES



1" GLASS VALVE

Special features of the Q.V.F. screw type 1" Glass Valve include a fluon plug and bellows which eliminate any form of packed gland, and it is particularly suitable for handling corrosive liquids at working pressures up to 50-lbs. p.s.i.

Descriptive folders of both items are available on request.

Q·V·F·
LIMITED
The Chemical Engineers in Glass

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STOKE-ON-TRENT · STAFFS
Tel: Longton, Staffs 32104-8
'Grams: Q.V.F., Stoke-on-Trent, Telex.

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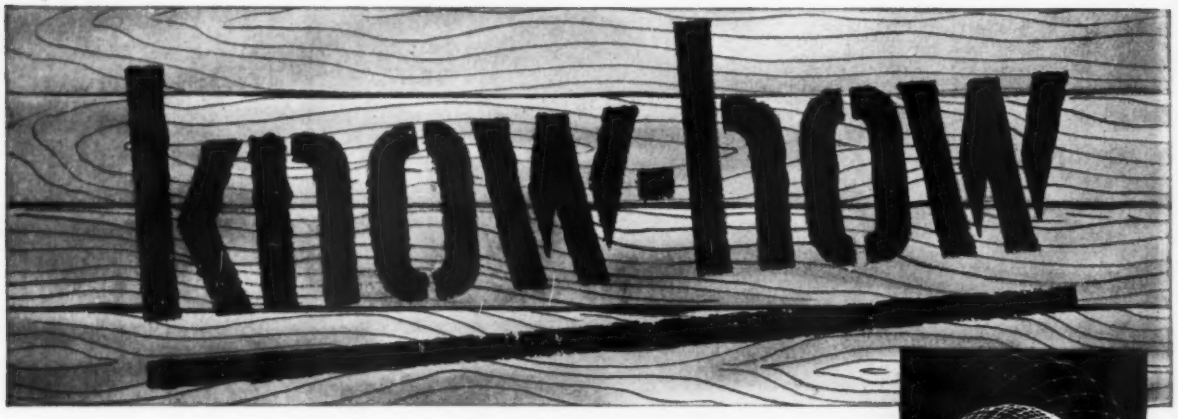
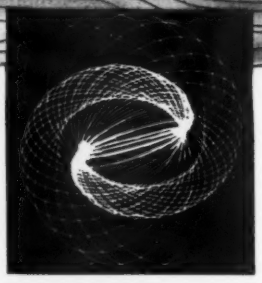


— the Stamp of experience which is on all Atomic Energy Equipment manufactured by Graviner. We can make almost anything in this rather new sphere of activity, whether it be a lead-filled shielded container, a Thulium storage magazine, a magnet for neutron beam focusing or a 20 ton mobile cell unit with viewing windows and handling equipment. We specialise too, in the machining of graphite. Indeed, with the recent addition of 12,500 square feet of factory space we can deal with anything from the making of a tiny graphite spring to a Reflector for a Reactor — all under controlled clean conditions. If therefore you have a Development or Production problem, our Nuclear Energy Division will be very pleased to help you. Won't you pay a visit to the Gosport Factory and see what we can do?



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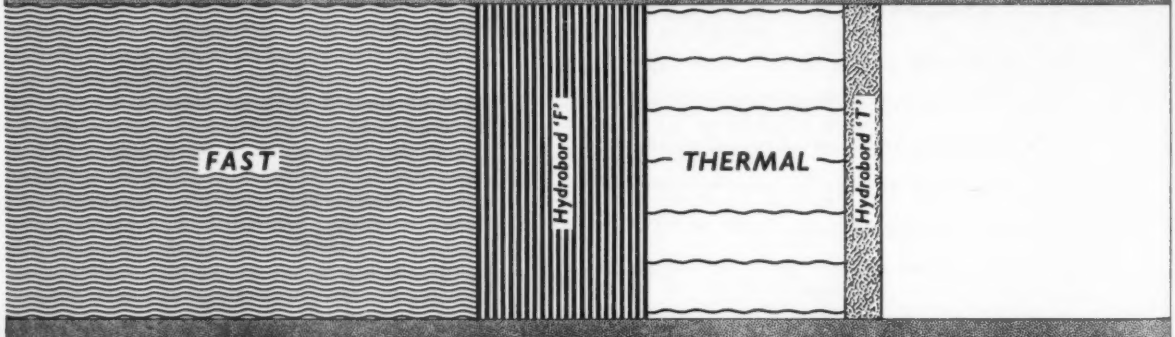
Contractors to The Atomic Energy Authority

FAREHAM ROAD · GOSPORT · HANTS · Telephone Fareham 2511

Also specialists in Airborne, Diesel Engine and Industrial Fire and Explosion Protection, Thermostats and Overheat Switches

'HYDROBORD'

NEUTRON SHIELDING



William Mallinson and Sons Ltd.

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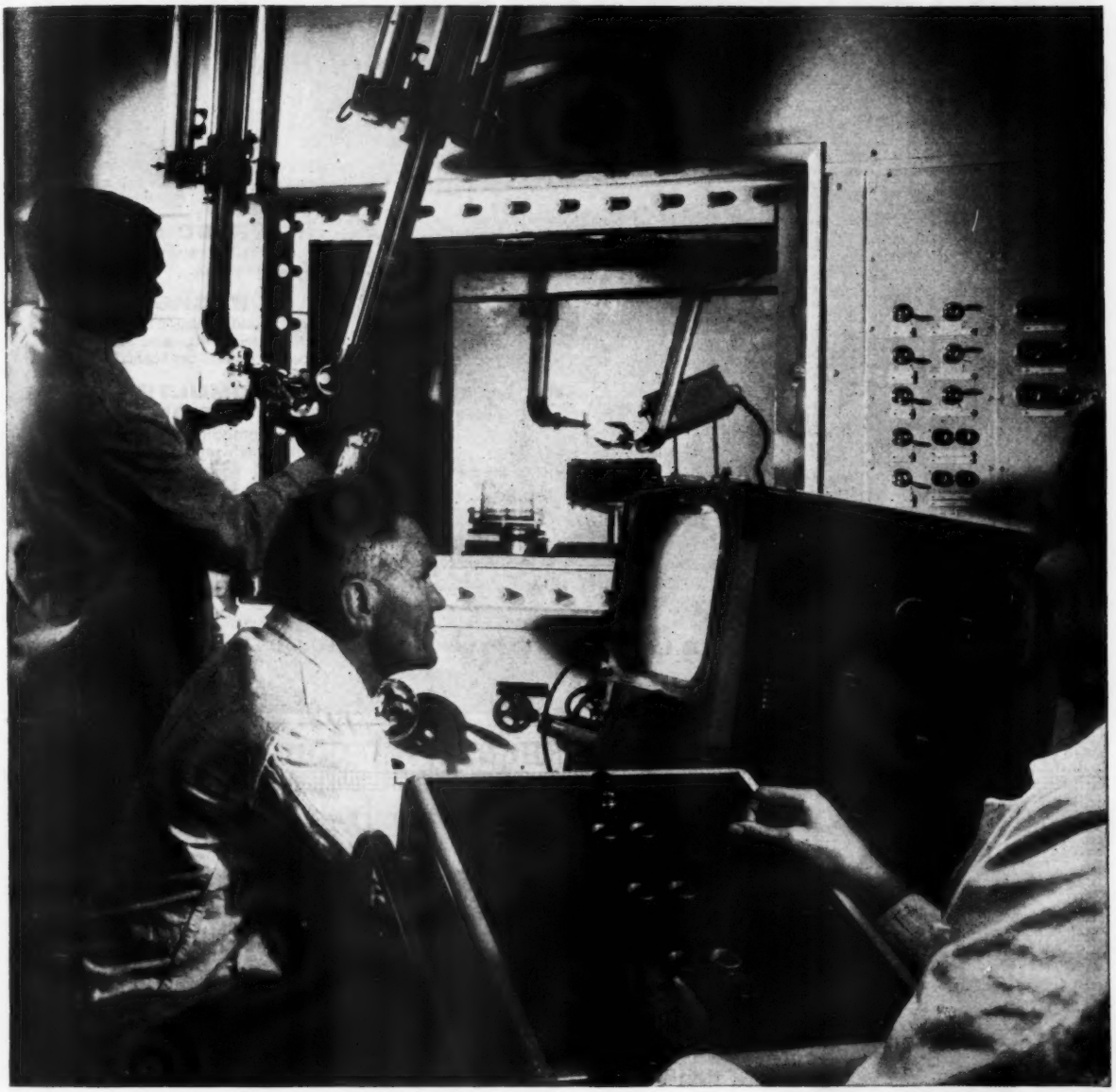

Pye at Dounreay

The Pye Instrument Group has supplied all the equipment to the U.K. Atomic Energy Authority for the irradiated fuel element laboratory at Dounreay. In addition to supplying equipment, Pye Ltd. acted as consultants and designers on all matters in that laboratory relating to instrumentation and remote handling. The illustration above shows manipulators working in conjunction with a television camera to handle and measure a sample from the fast reactor.

The Pye Instrument Group consists of: Pye Atomics Division; Pye Industrial Television Division; Faraday Electronic Instruments Ltd.; Labgear Ltd.; W. G. Pye & Co. Ltd.; Pye Telecommunications Ltd.; Unicam Instruments Ltd.; W. Bryan Savage Ltd.; W. Watson & Sons Ltd.

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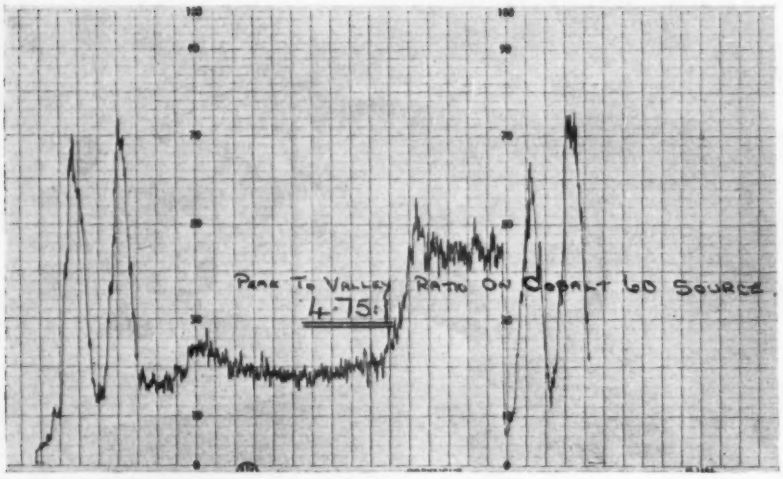
AN EXTRA-SENSITIVE PHOSPHOR

Crystal-with-Photomultiplier



The thallium-activated sodium iodide crystal is mounted direct on a photomultiplier.

HIGH RESOLUTION
Peak-to-valley ratio of 4:1 with a Cobalt-60 source.

LOW BACKGROUND
Background radiation is due entirely to Potassium-40, and does not exceed 8 counts per second.

PHOTOMULTIPLIER PROTECTION
The photomultiplier is never exposed to direct light, and so its efficiency is preserved.

3-inch assemblies and 1-inch counting probes. Catalogue CJ 39/b55 for details.

HILGER & WATTS

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FLAMEPROOF PRESSURE SWITCH

Designed to meet the requirements of BSS 299 for operation in hazardous atmospheres, and incorporates a stainless steel pressure element. Fully approved by the Ministry of Fuel and Power for Group 1, also 2 and 3 gases.

Pressure ranges for Type SP-1027 from 0-20 p.s.i. to maximum 300 p.s.i. Other Buxton Certified Flameproof Pressure Switches available for ranges 30" w.g. to 5,000 p.s.i. and 0-30" Hg. vacuum.

FULL DETAILS AND SPECIFICATIONS OF THE COMPLETE K.D.G. RANGE ARE READILY AVAILABLE FROM:

K.D.G. INSTRUMENTS LTD IN ASSOCIATION WITH STOW & PARTNERS LTD
MANOR ROYAL · CRAWLEY · SUSSEX TEL.: CRAWLEY 25151
LONDON SHOWROOMS, SERVICE AND SALES: 100 FLEET STREET, LONDON, E.C.4. Telephone: FLEet 5354/5

CRAWLEY KDG LONDON

WANTED

This man is not only repulsive but dangerous. Heavily disguised as a Buyer, he has been shown up as an impostor by his persistent failure to see that **ASSOCIATED LEAD** are a highly economical and reliable source of Lead and Antimony in all their forms, and particularly of **LEAD, TIN, ANTIMONY AND THEIR ALLOYS; 99.999% PURE LEAD, TIN AND ANTIMONY; SOLDERS; ANTIFRICTION METALS; ANTIMONIAL LEAD; CABLE ALLOYS; LEAD SHEET AND PIPE; DENSE LEAD SHIELDING FOR NUCLEAR WORK.** His firm are now out for his blood, if any.

This announcement is issued for and on behalf of

ASSOCIATED LEAD MANUFACTURERS LIMITED

CLEMENTS HOUSE, 14 GRESHAM STREET, LONDON, E.C.2. CRESCENT HOUSE, NEWCASTLE. LEAD WORKS LANE, CHESTER

Export enquiries to: Associated Lead Manufacturers Export Company Limited, Clements House, 14 Gresham Street, London, E.C.2.

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Brobdingnagian or Lilliputian?

It is improbable that Dean Swift had any thoughts about ball bearings in his curious romancings, but he would, we believe, appreciate the well-balanced design and fine finish of both our big and little fellows.

We have made bearings as large as 5 ft. diameter to support a locomotive turntable whilst their tiny counterparts, some as small as 3 mm. diameter, may be used on a very high speed dental drill, or perhaps for an instrument where the need is not for speed but extremely sensitive motion.

These Lilliputians of engineering are held to B.S.I. limits of accuracy or to the American specifications ABEC 3, 5 or 7.

HOFFMANN

PRECISION MINIATURE BALL BEARINGS

THE HOFFMANN MANUFACTURING CO. LTD., CHELMSFORD, ESSEX

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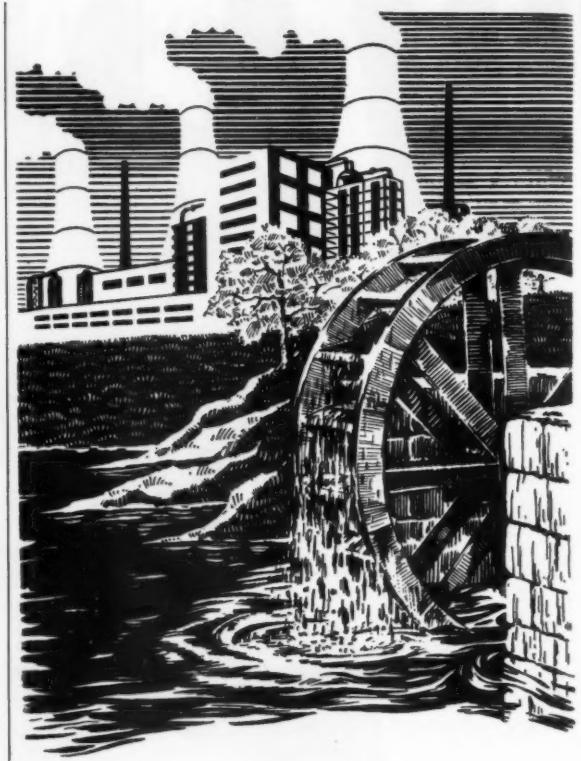

WATER

is still in the foreground...

However revolutionary the methods of producing power may become, water is still all-important; and the need to give complete and lasting internal protection to water tanks in modern plants remains paramount.

With a reputation consolidated over 30 years of successful use **BITOTES Solution and Enamel** prevents interior corrosion of all steel and concrete water containers and conduits. BITOTES cannot crack or peel and is tasteless and odourless when dry. It is fully approved for Fresh Water, Drinking Water, Demineralised Water, etc.

May we send you details

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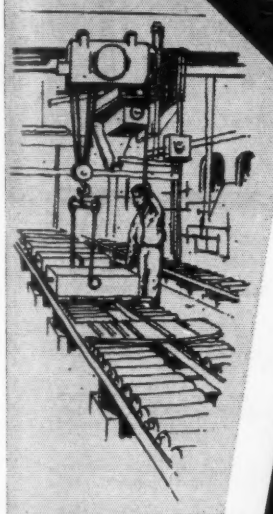
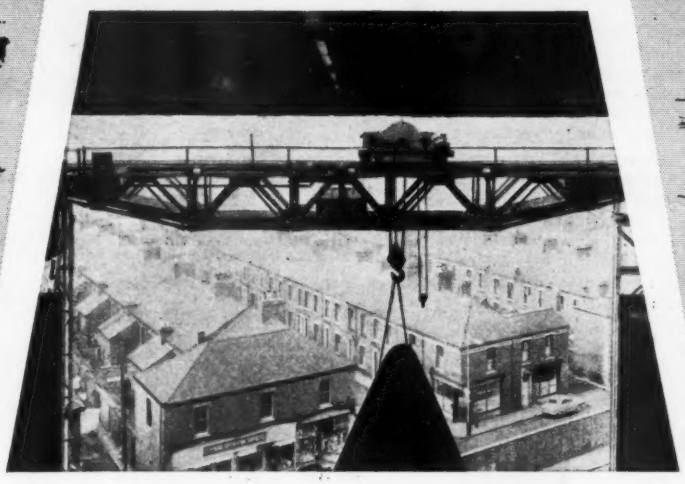
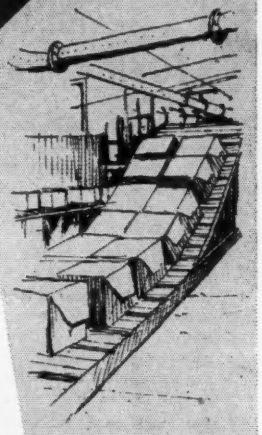
PATERSON HUGHES
ENGINEERING COMPANY LIMITED





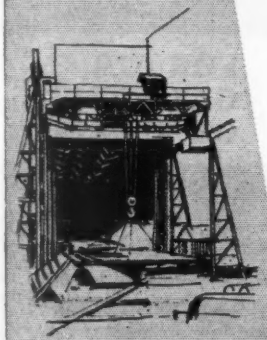


A Paterson Hughes 30-ton electric overhead travelling crane at Blyth Dry Dock and Shipbuilding Co. Ltd.—by whose courtesy this photograph is reproduced.

Paterson Hughes cranes are built in their modern crane shop in Scotland to designs based on their 35 years of experience in this field.

If the Paterson Hughes range—from hand jibs to 100-ton overhead cranes—does not include a standard model suited to your exact needs, then a special will be designed at a competitive price.

Paterson Hughes engineers will also design complete crane systems, extending from your goods inwards bay to the finished products warehouse, bearing in mind the special requirements of each industry.



THE PATERSON HUGHES

CRANE DIVISION

Specialists in modern crane practice

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P.2114

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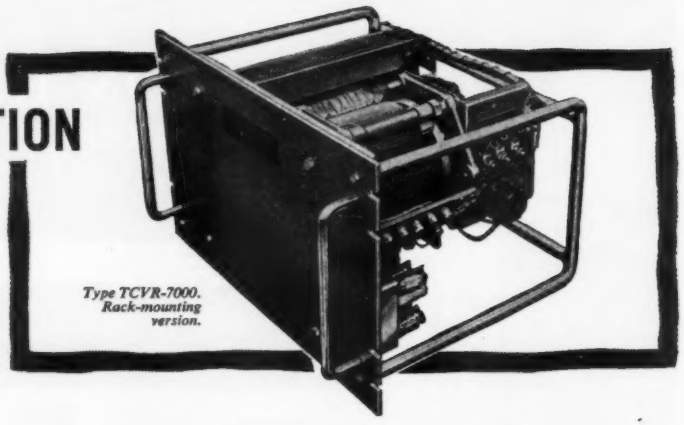
40 VOLTS/SEC AUTOMATIC CORRECTION

—with the type TCVR voltage regulator



Type TCVR-7000. Rack-mounting version.

The TCVR is a servomechanical automatic voltage regulator having the very high speed of correction of FORTY VOLTS PER SECOND. It provides an *undistorted* output, maintained constant within very close limits (normally ±0.5%) from no-load to full-load, for wide variations in frequency and power factor.

A wide range of models from 1.6 to 12 kVA single-phase, and 4.8 to 36 kVA three-phase, is available, to standard or tropical specification, in cabinets or for rack-mounting. Models are also available in which the output voltage is continuously adjustable over a wide range by means of a panel control. Regulators can be supplied to Services' specification, and special models can be designed to order.

For high-speed, accurate stabilisation *without distortion*—**specify TCVR.**

Claude Lyons Ltd.

Other products of Claude Lyons Ltd. Stabiliser Division

BMVR: Motor-driven laboratory and industrial regulators ranging from 1·6 to 29 kVA single-phase, and 4·8 to 87 kVA three-phase. Constancy of output normally ± 0·5% from no-load to full-load. No distortion. Speed of correction 1 Volt/Sec. A great variety of models, standard, tropical and militarised, for all applications.

BAVR: Electronic stabilisers of very high accuracy, and very rapid response, with no moving parts. Input range: − 10% to + 5%, output constancy ± 0.15%. Three sizes: 200, 500 & 1000 VA. Exceptionally useful for control of chemical processes, heating, lighting, etc.

ASR: Automatic step regulators, small, inexpensive, and with sinusoidal output waveform. Two sizes: 1·15 kVA and 2·3 kVA. Input range − 10% to + 5%; output constancy, ±2½%.

ATC: Automatic Tap-Changing Transformers — a development of ASR. Two sizes: 575 VA and 1150 VA. Input range − 20% to + 10%: output constancy, ± 5%. Provide adequate stabilisation for many types of apparatus, at low cost. Also useful as pre-regulators, e.g. in conjunction with BAVR.

We shall be pleased to send you full details of our entire range.

Stabiliser Division **VALLEY WORKS · HODDESDON · HERTS · TELEPHONE HODdesdon 4541 4**

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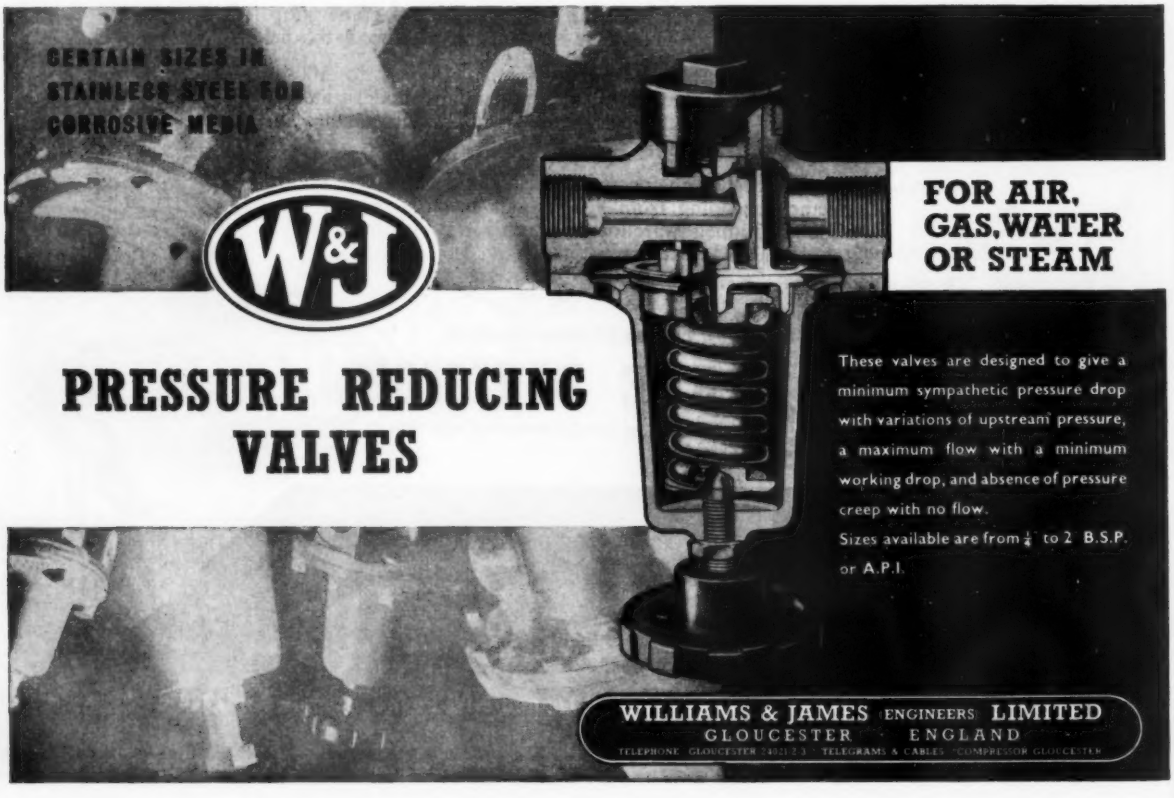

PRESSURE REDUCING VALVES

FOR AIR, GAS, WATER OR STEAM

These valves are designed to give a minimum sympathetic pressure drop with variations of upstream pressure, a maximum flow with a minimum working drop, and absence of pressure creep with no flow.

Sizes available are from ¼" to 2" B.S.P. or A.P.I.

WILLIAMS & JAMES ENGINEERS LIMITED
GLOUCESTER · ENGLAND
TELEPHONE GLOUCESTER 24021-2-3 · TELEGRAMS & CABLES "COMPRESSOR GLOUCESTER"

IMPAX

Regd. Trade Mark No. 719,268

FOR SHAFTS ROTATING AT
HIGH SPEEDS COUPLED WITH
HIGH FLUID TEMPERATURES
AND PRESSURES

Illustrated is a sectional view of a C.B.A. type seal with contact ring

Catalogue supplied on request

CHARLES WESTON & CO. LTD.

IRWELL BANK WORKS, DOUGLAS GREEN, PENDLETON, SALFORD 6
TELEPHONE: PENDLETON 2857, TELEX: 66-255
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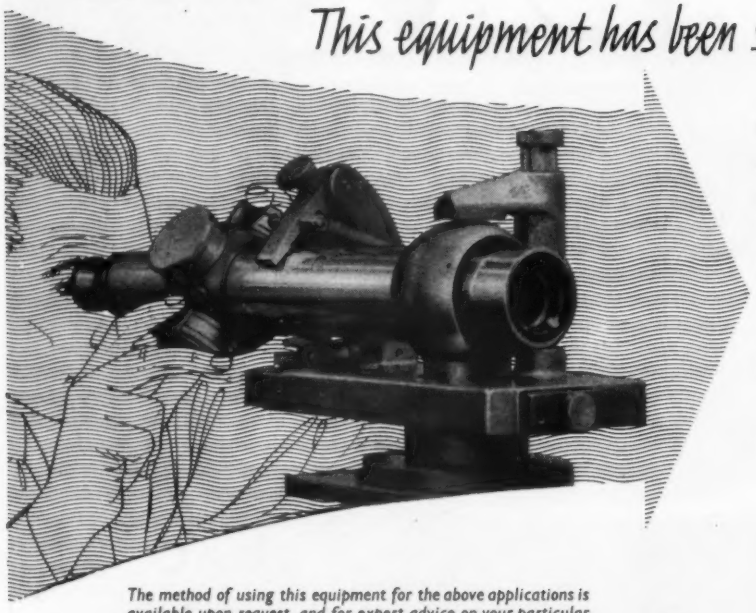
'MICRO' ALIGNMENT TELESCOPE

This equipment has been successfully used by . . .



. . . the United Kingdom Atomic Engineering Research Establishment in the construction of Experimental Nuclear Reactors and the associated Projects ZETA, BEPO, ZEUS, ZEPHYR, DIDO and PLUTO. Also used by the leading manufacturing groups in the construction of Nuclear Power Stations, of the Power Supply Plan in Great Britain.

Sets and checks **ALIGNMENT PARALLELISM·SQUARENESS PLANE SURFACES**

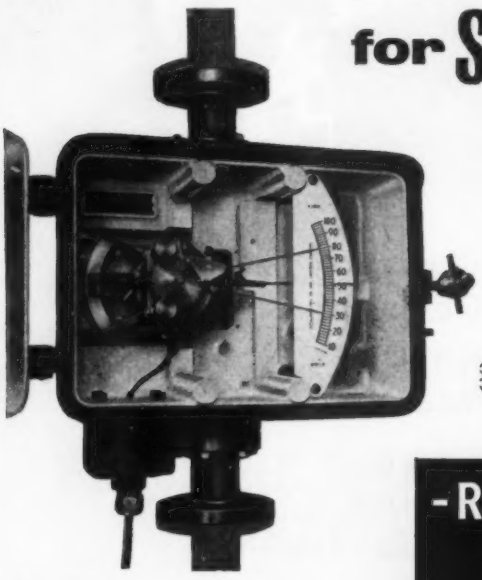
The method of using this equipment for the above applications is available upon request, and for expert advice on your particular problem, please apply to Optical Tooling Engineers' Dept.

A Division of RANK PRECISION INDUSTRIES LTD.

TAYLOR-HOBSON

TAYLOR, TAYLOR & HOBSON, LEICESTER, England. AT 29

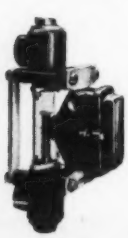
for SAFETY in your pipeline



Where a change of liquid or gas flow rate is dangerous then one of these Rotameter flow alarms can be used to provoke attention. Electric or pneumatic signals provide visual or audible alarm.

For details of the instruments shown here, please write for leaflet NP.2010/24.

-Rotameter flow alarms



Type 750

Metric Series

Type 825A

Type 500A
Electric or pneumatic signal, fully adjustable, for liquids or gases.

ROTAMETER
FLUID MEASUREMENT AND CONTROL
FLOW-DENSITY-LEVEL

ROTAMETER MANUFACTURING CO. LTD
330 PURLEY WAY, CROYDON, SURREY
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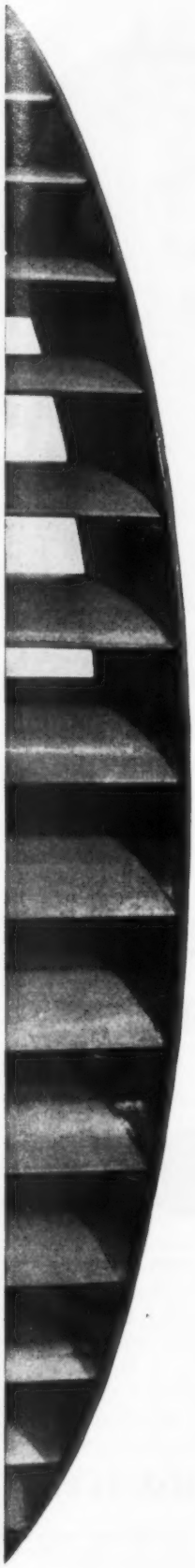
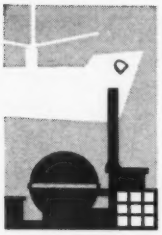
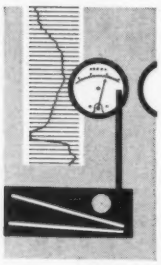
G.24



formula for leadership



Experience Founded originally in 1823 the Company has had the widest experience in the design and manufacture of all types of equipment for the handling of air and other gases. Blowers, exhausters, heaters, filters, dust and fume removal equipment, and of course, fans of all types, fall within this wide scope. Fans of every size and for every purpose, from Coal Mines to Aircraft Carriers, have been designed, manufactured and tested by Keith Blackman and installed in all parts of the world—experience unparalleled in the field.

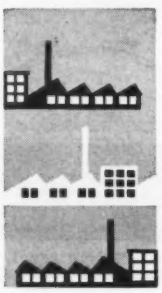


Research Keith Blackman's lead in design is maintained by five separate research departments. Specialised facilities are available at Tottenham for the development and testing of axial fans, centrifugal fans and filtration equipment, while a metallurgical laboratory controls the quality of materials founded at Arbroath. Tottenham also possesses one of the most advanced acoustics laboratories in the world for the investigation of sound levels in all types of fan engineering equipment.
In addition, the company's generating station, as well as supplying power to the factory, is designed to produce a wide range of A.C. and D.C. supplies for the test beds.

Range The Keith Blackman range covers virtually every type of fan and blower in all sizes—axial types from 5 inch to 100 inch diameter, centrifugal types ranging from 1½ inch to 180 inch, and propeller fans from 6 inch to 72 inch diameter. Much equipment is designed for clients' specific requirements involving, frequently, the use of special materials including pvc. Other equipment is made for heating, cooling, washing, dust and fume extraction, filtration and air conditioning. *Five thousand fans of varying types are kept continuously in stock for quick delivery.*

Keith Blackman Ltd
(incorporating Blackman Export Co. Ltd.)
MILL MEAD ROAD, LONDON N.17 TOTTENHAM 4522

Leaders in the Fan Industry



Resources The company's three factories cover an area of 17¼ acres, and employ over 1,800 people. The main Tottenham works produces small and medium units and includes drawing offices, test facilities and machine shops, as well as the sales and administration offices.
The Arbroath works deals with the production of the larger fans. Its iron and non-ferrous foundry plant supplies the whole of the company's casting needs.
The Edmonton Factory concentrates on light sheet metal and plate work and the fabrication of steel structures.
Virtually all components, including fan motors and bearing housings, are thus designed and manufactured within the organisation—a unique combination of resources.

Service Through the years the company has built up an enviable reputation for service at all stages. Sales representatives are all fully trained technical men capable of giving 'on the spot' advice on routine applications or special problems. The sales organisation operates from branches throughout the country backed by a staff of qualified sales engineers at Head Office.
Despatch of stock items, of which 5,000 units are kept continuously available, is possible in as little as four days. The Company has its own road transport fleet and direct rail connections from the main factory.

Tornado/1044

Circle **No 85** on reply card for further details

Circle **No 86** on reply card for further details

"B-W" VACUUM OVENS

The Vacuum Oven illustrated is supplied in various sizes for drying, de-gassing and other processes requiring vacuum treatment. It is typical of Barlow-Whitney's extensive range of Industrial Process Heating Equipment which includes—

FURNACES · PROCESSING OVENS
HUMIDITY CHAMBERS
MELTING POTS
HEATED AUTOCLAVES
FLOWLINE HEATERS

Write for further details quoting reference C860

PROCESS HEATING — Barlow-Whitney

Tel: AMBassador 5485/6

BARLOW-WHITNEY LTD., 2 Dorset Square, London, N.W.1
Works: London & Bletchley

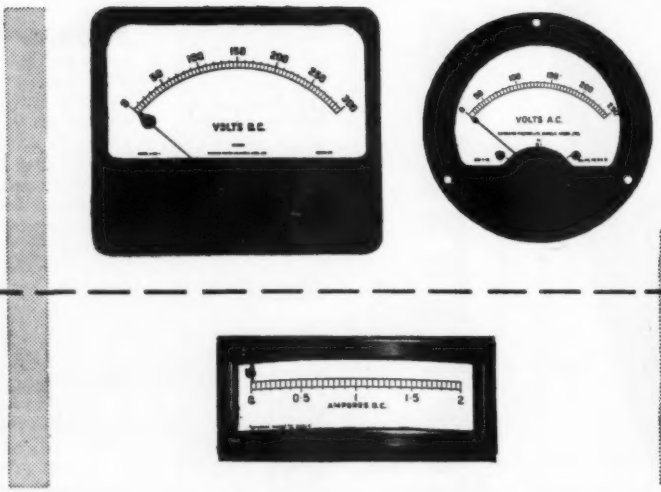
BMJ

WESTON PANEL INSTRUMENTS

Complete flexibility in panel design is made possible by the Weston range of "miniatures" which includes round, rectangular and edgewise models. Round models are housed in cases of 2", 2½" and 3½" diameter . . . or, to harmonise with rectangular panels, the rectangular type is available, giving an increase in scale length of approximately 50% over the equivalent round models. Horizontal edgewise instruments are available with scale lengths of 2½" and 3½".

Moving iron, moving coil, a.c. rectifier and h.f. thermocouple models are offered—all with the accepted Weston qualities of accuracy and reliability.

Full particulars are to be found in leaflets—Lists Nos. W1, W2, W3 and W4, copies of which are available on request.



SANGAMO WESTON

SANGAMO WESTON LTD • ENFIELD • MIDDLESEX

Tel: ENField 3434 (6 lines) & 1242 (6 lines). Grams: Sanwest, Enfield.

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SW/68

FINE-GRAIN even at X20

Mr. G. B. Higgins, Chief Radiologist in the Public Test House of Vickers-Armstrongs (Aircraft) Limited was asked by a customer* to examine batches of mineral-insulated thermocouple wires obtained from various suppliers for use in nuclear reactor test rigs. He was asked to compare the wires for thickness of sheath, thickness of conductors, and concentricity of conductors inside the sheath.

The materials were a few thousands of an inch thick (the largest wire being only 1/16th-inch in diameter) so it would be necessary to project magnified images of the radiographs on to a screen. A film with very high contrast and the finest possible definition was necessary, so Mr. Higgins chose 'Industrex' film Type M.

The technique was to use low-kilovoltage X-rays at a large film-focal distance. Firm contact was maintained between wire and film, and the radiograph was slightly under-exposed to avoid the chance of getting false readings because of undercut.

The radiograph was viewed on a universal gauge projector in Vickers' metrology laboratory at Swindon. All the required information, correct to within 1% of the actual material thickness, was obtained easily at a magnification of X20.

Spot radiography was carried out in this way throughout the 75-foot lengths of thermocouple wire to ensure that the very high standard demanded in nuclear research was maintained.

Where the requirements are for the finest possible resolution with very high contrast there is no better material than Kodak X-ray Film Type M.

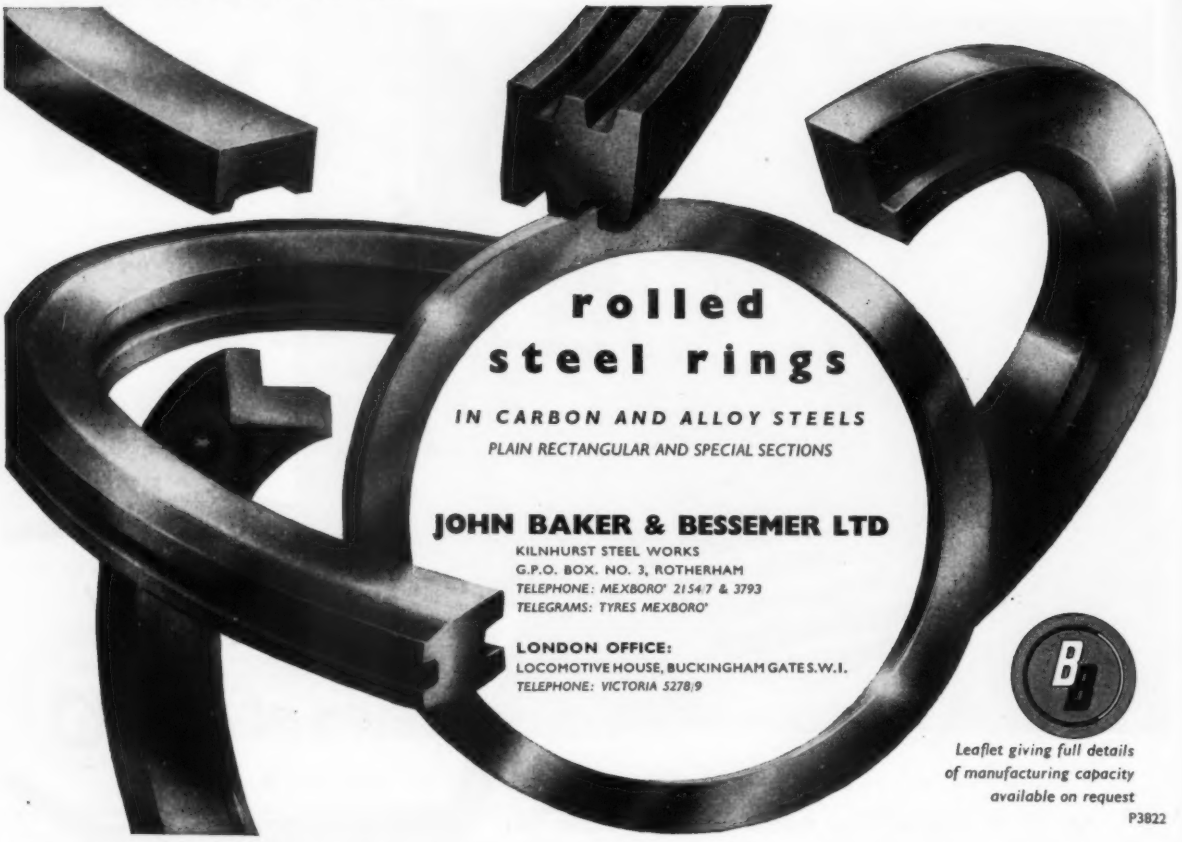
*The extensive Test House facilities of Vickers-Armstrongs (Aircraft) Limited are available to users on a commercial basis.

Kodak

'INDUSTREX' X-RAY FILM TYPE M

In previous announcements in this journal we have listed various Kodak publications which describe the many industrial applications of photography and radiography. These publications are free, and appropriate literature will be sent to you with pleasure if you will let us know your particular interests.

Kodak Limited, Industrial Sales Division, Kodak House, Kingsway, London, W.C.2



Leaflet giving full details of manufacturing capacity available on request

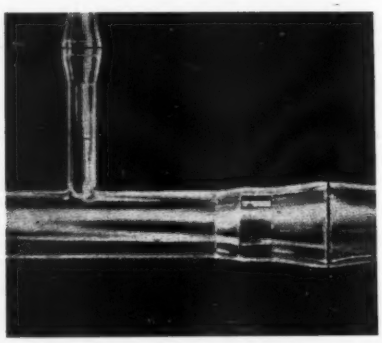
P3822

Put it together faster..

with

VITREOSIL

BUTTRESS JOINTS



For easily assembled joints between pilot plant pipelines and apparatus these joints are ideal.
Buttress Joints with smooth ground flat faces ensure a robust seal with a simple gasket.
Available separately or fused to tubing or apparatus, these joints are secured with a simple clamp and are not liable to seize up with such materials as silicon tetrachloride.

- **EASIER TO ASSEMBLE**
- **SAFER IN USE**
- **GREATER FLEXIBILITY**

TSL

THE THERMAL SYNDICATE LTD.

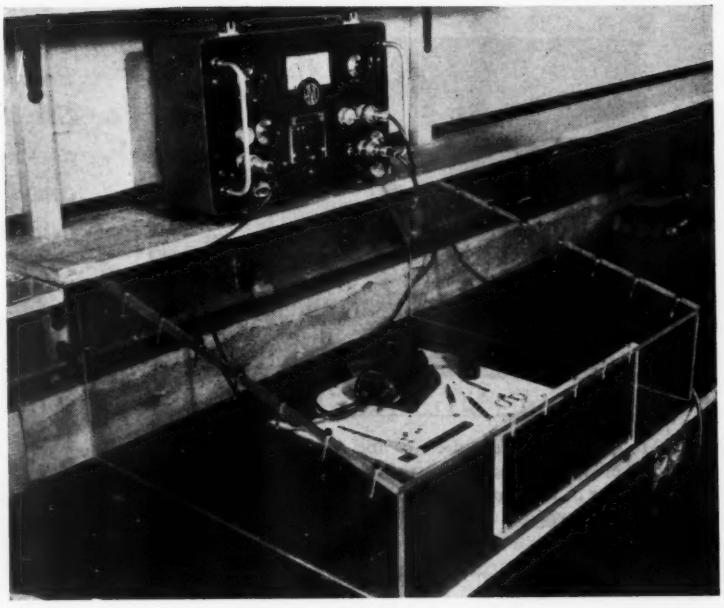
P.O. BOX No. 6, WALLSEND, NORTHUMBERLAND. *Tel. 62-3242/3*

LONDON: 9, BERKELEY STREET, W.1. *Tel. Hyde Park 1711/2*

AVO in action . . .

The photograph shows an AVO "D.C." Amplifier Type 1388B being used to measure current of the order of 10^{-13} A in the ionisation chamber of an "Avo" Radiac Survey Meter. A radio-active source is being used to calibrate the instrument and a Perspex screen is employed to protect personnel from Beta radiation.

This is a typical example of how the AVO organisation, working in conjunction with Government research authorities, continues to make its contribution in the fields of modern scientific development and industrial progress.



AVO Instruments :—

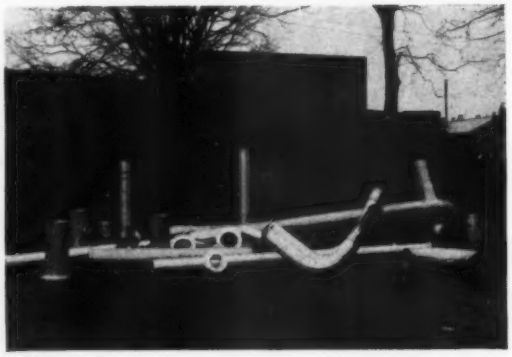
Model 8 AvoMeter
Model 40 AvoMeter
Panclimatic AvoMeters
Electronic Test Meters
Valve Tester Type 160
Universal Measuring Bridge Type 1
D.C. Amplifier Type 1388B
Model 7 AvoMeter
Heavy Duty AvoMeter Mk. V
Signal Generators
Electronic Test Unit
Valve Characteristic Meter Mk. IV
Electronic Multimeter Type 38
Radiac Survey Meters

A fully descriptive Brochure is available on request for each of the Avo Instruments listed above.

AVO Ltd. AVOCET HOUSE · 92-96 VAUXHALL BRIDGE RD. · LONDON · S.W.1
Telephone: VIC 3404 (12 lines)

Manufacturers of ELECTRICAL, ELECTRONIC & NUCLEONIC INSTRUMENTS and DOUGLAS & MACADIE COIL WINDING MACHINES
A MEMBER OF THE METAL INDUSTRIES GROUP OF COMPANIES

Specialists in Aluminium Alloy Plate and Structural Fabrications of all descriptions



One of the first users of the Argon Arc welding process in the country, we again lead in the installation of the Sigmette Fine Wire welding equipment which opens a new field in the welding of Aluminium and its alloys, Non-Ferrous metals and Stainless Steels

Heat Exchangers
Pressure Vessels
Structural Aluminium of all descriptions
Smooth bore pipes and fittings up to 24" diameter

Your enquiries would receive our immediate attention

Illustrated is an 8" and 12" Bore Pipe installation fabricated for the Ministry of Supply

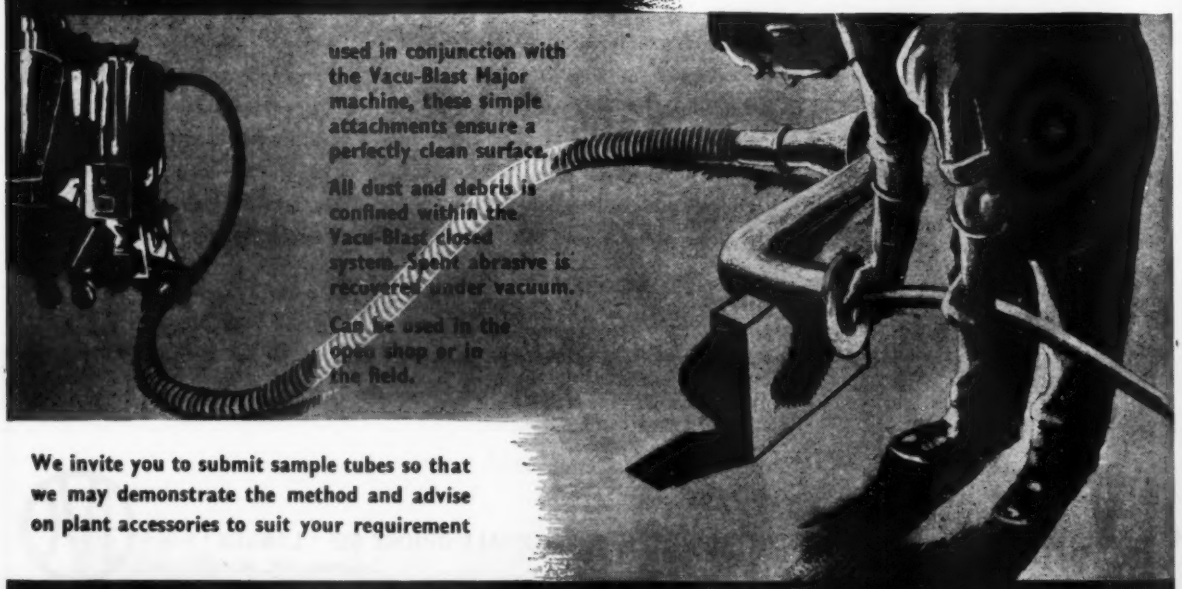
E. C. PAYTER & CO. LIMITED

MEETING ST., GREAT BRIDGE, TIPTON, STAFFS. *Tel.:* TIPTON 2121

VACU-BLAST

for shot blasting tubes of any size from ⅛ inch bore upwards

the only effective way to remove scale, fused sand and corrosion products from the internal surface of tubes of practically any shape or size.



used in conjunction with the Vacu-Blast Major machine, these simple attachments ensure a perfectly clean surface.

All dust and debris is confined within the Vacu-Blast closed system. Spent abrasive is recovered under vacuum.

Can be used in the open shop or in the field.

We invite you to submit sample tubes so that we may demonstrate the method and advise on plant accessories to suit your requirement

VACU-BLAST LIMITED, BATH ROAD, SLOUGH, BUCKS, ENGLAND.

TELEPHONE: SLOUGH 24507/9

Cut the 'down' time

TYPES

INDUSTRIAL for general industrial use up to 660 V.

SHOCKPROOF where resistances are subjected to heavy vibration—extra support for grid rods and heavier sides.

STEEL WORKS with bakelite secondary insulation of grid rods. This type can be supplied with the extra rod supports to resist excessive shock if necessary.

DRAW-OUT. Each bank of grids is carried on a slide so that it can be quickly replaced. This feature can be supplied to any of the above types.

FLAMEPROOF. Totally enclosed in welded steel cases to comply with B.S.229/1957. Flameproof certificate numbers FLP 1085 and FLP 3233.

The use of E.M.B. draw-out resistances ensures the speedy replacement of grid banks when necessary.

Simply remove the 2 set pins and slide out the grid bank without straining or lifting!

There's no need to have space back and front——if it's arranged to withdraw from the front, there's no room needed at the back and vice versa.

Specify E.M.B. to reduce maintenance.

We can give quick delivery!

E.M.B. Co. Ltd.

West Bromwich ———— England

Consignment of draw-out resistances for a well-known steel works.

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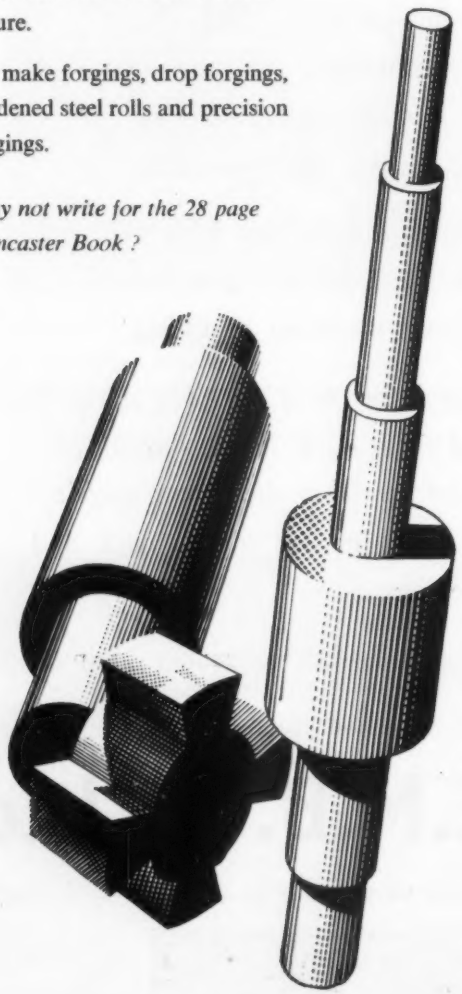
Circle **No 95** on reply card for further details

Famous for Forgings

The Daniel Doncaster companies never stand still — we are always putting in extensive (and expensive !) new equipment to enable us to undertake by a combination of processes and plant work of the most versatile nature.

We make forgings, drop forgings, hardened steel rolls and precision forgings.

Why not write for the 28 page Doncaster Book ?



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DANIEL DONCASTER & SONS LIMITED SHEFFIELD

MONK BRIDGE IRON & STEEL CO. LEEDS 12
MOORSIDE COMPONENTS · OLDHAM
DANIEL DONCASTER & SONS (THE BLAENAVON CO. BRANCH) LTD.
BLAENAVON · MONMOUTHSHIRE

F.82

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HAIR OR AIR?

Both! One used in conjunction with the other! That's been our business for a long time and we've built up a vast stock of experience and know-how in the process!
Every Heather Air Filter uses a finely graded screen of intermingling hair to trap dust particles and impurities from the incoming air-stream. And, what's most important, this unique, low-cost filter system does not need special cleaning equipment, fluids, replacement pads or fabrics. So why waste money on expendable filter elements and replacements when a Heather Filter can be cleaned for further use simply by shaking, washing or suction cleaning?
If *you* want full details write for our new catalogue No. 41.

Here is a Heather Multi-Brush Air Filter But do you also know about our range of money-saving Satomair Humidifiers? Send for our new catalogue and we'll forward details of these as well.

HEATHER FILTERS LIMITED

7 KENDALL PLACE · BAKER STREET
LONDON · W.1. HUNTER 1801

SERVICE DE RENSEIGNEMENTS POUR NOS LECTEURS

Il est souvent difficile au client publicitaire d'indiquer dans un espace restreint tous les détails de ses produits. Dans le cas où vous désireriez de plus amples renseignements à ce sujet, veuillez pointer le numéro approprié sur la carte ci-contre et envoyer cette dernière à NUCLEAR POWER

AUSKUNFTSDIENST FÜR LESER

Es ist oft schwierig für Inserenten alle technischen Einzelheiten über ihre Produkte in einem begrenzten Platz zu bringen. Sollten Sie noch weitere Auskünfte wünschen, streichen Sie einfach die bestimmten Nummern auf der nebenstehenden Karte an, und senden Sie sie an NUCLEAR POWER

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E' talvolta difficile all'inserzionista di indicare in uno spazio ristretto tutti i particolari dei suoi prodotti. Qualora desideraste ricevere più ampie informazioni a questo riguardo, favorite segnare il numero appropriato sul cartellino qui accanto ed inviare quest'ultimo a NUCLEAR POWER

SERVICIO DE INFORMACIÓN PARA EL LECTOR

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Информация для читателей

Часто бывает трудно рекламирующим лицам давать все технические подробности своей продукции в рекламе. Если Вам понадобятся добавочные сведения, то просто отметьте соответствующие номера на наточке на противоположной стороне и отправьте в NUCLEAR POWER

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在廣告上以有限的地方來解釋一些專門技術 及它們的効果 的確是有受限制的困难若請意欣賞和進一些詳細的情形就請將对頁的表格 取一號下來將閣下有疑问的項目 同笔勾一下郵寄給子能工經處即可。

讀者サービス

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Nuclear Power

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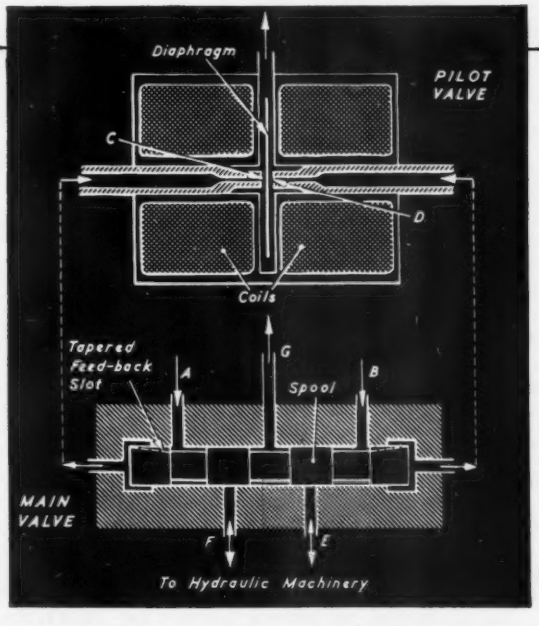
TYPE A·W·E 144/5 ELECTRO-HYDRAULIC SERVO VALVE

This electro-hydraulic servo valve, developed by Armstrong Whitworth from their successful aircraft unit, can be used to control a wide range of hydraulic machinery and is particularly suited to process control systems. The valve utilizes hydraulic rather than electrical power amplifications and has a remarkably high power gain. A diaphragm, clamped around its periphery by two coil housings, is used to control the power — instead of the usual torquemotor — and the valve is therefore not susceptible to vibration effects.



The valve — see diagram — consists of a main valve and a pilot valve. The main valve is supplied with pressure oil through ports A and B. When the spool is in the central position — as shown — the oil escapes through the tapered slots to the opposed jets C and D in the pilot valve and impinges on each side of the diaphragm. The two coils can be energised to attract the diaphragm towards one or other of the jets. If the signal to the right hand coil is the stronger, the diaphragm will flex to the right, restricting the flow from the right hand jet and thus increasing the pressure in that line. Similarly, the pressure in the left hand line is reduced. This pressure difference is transmitted to the main valve and causes the spool to move to the left until the resultant decrease in discharge area of the tapered slot at the right hand end of the spool and the increase in that at the left cause equilibrium to be restored. The displacement of the spool uncovers ports E and F, thus opening pressure and return lines to the hydraulic machinery.

ARMSTRONG WHITWORTH EQUIPMENT HUCCLECOTE, GLOUCESTER · TELE: GLO 67011

SIR W. G. ARMSTRONG WHITWORTH AIRCRAFT LTD., A MEMBER OF THE HAWKER SIDDELEY GROUP

AI's extensive field laboratory is located in California's Santa Susana Mountains. *Woodcut by Edward Kysar.*

How can A.I. facilities help you plan a Nuclear Program?

In the picturesque Santa Susana mountains near Los Angeles, Atomics International has built an extensive field laboratory for research, engineering and testing in the nuclear sciences. Here, and at a headquarters complex in the valley below, men who pioneered the creative uses of atomic energy are applying their experience to develop advanced nuclear reactors and associated equipment.

Fourteen years of experience in developing various types of reactors for the Atomic Energy Commission and other organizations have given the men of Atomics International a collective background unparalleled in the industry. The facilities at their disposal are among the most sophisticated and extensive in the world.

Results of AI's work have been demonstrated in projects for the AEC which include the Organic Moderated Reactor Experiment at the National Reactor Testing Station in Idaho and the Sodium Reactor Experiment at the company's field laboratory. Additionally, AI built and is operating SNAP II, a 220 pound prototype reactor to produce three kilowatts of electricity for space vehicles.

Atomics International is also building large power reactors for electric utilities in Ohio and Nebraska under AEC programs. Studies are underway for other power reactors in the United States and Europe. Research reactors have been built by AI for Denmark, Germany, Italy. Japan, Puerto Rico and several sites in the United States.

For details contact: ATOMICS INTERNATIONAL, Canoga Park, California, U.S.A. Cable address: ATOMICS.

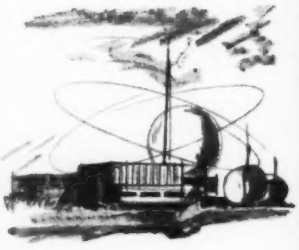
ATOMICS INTERNATIONAL
A DIVISION OF NORTH AMERICAN AVIATION, INC.
PIONEERS IN THE CREATIVE USE OF THE ATOM

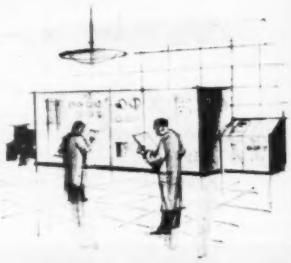
Other offices in: Washington, D.C., U.S.A.; Geneva, Switzerland. Affiliated with: INTERATOM, Bensberg/Cologne, Federal Republic of Germany and DYNATOM, Paris, France.

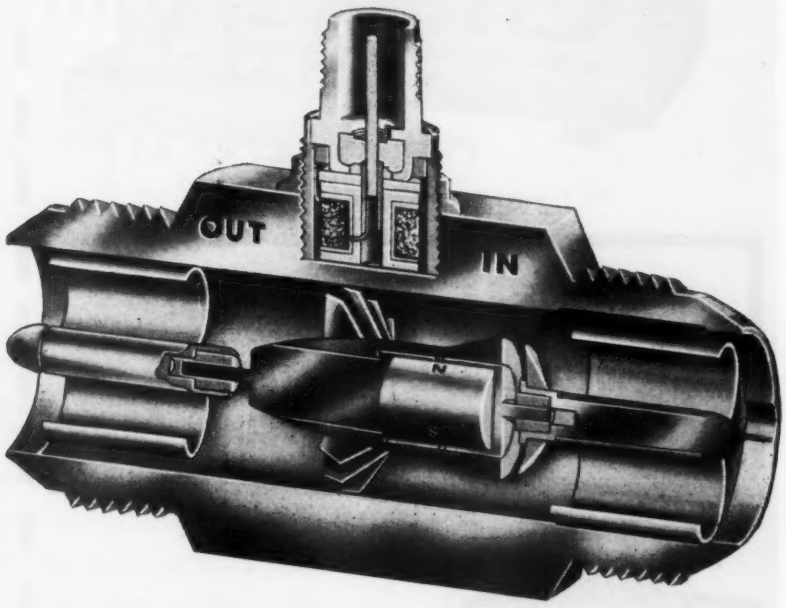
Wherever information on fluid flow is required,

the de Havilland POTTERMETER

sets new standards of accuracy and reliability







This new turbine-type flowmeter enables major advances to be made in the techniques of flow measurement and control. The de Havilland Pottermeter is the only flowmeter which offers all these features:

Contains only one moving part—no thrust bearings—operates with a minimum of maintenance at high temperatures and pressures

Accuracy to ± 0·1% or better on repetition work, ± 0·5% or better over a 20·1 range. Calibration remains constant for a variety of liquids over wide flow ranges.

No larger than the pipeline in which it is installed—may be mounted in any attitude.

Can be supplied with indicating, recording and process control equipment— gives digital presentation of results.

Can measure volumetric or mass flows.

Models available to measure flows from 0·1 to 40,000 Imperial gallons per minute, at a wide range of operating pressures. Larger and smaller sizes made to order.

Can measure flow of any liquid or gas, irrespective of its lubricating or non-lubricating properties, at temperatures ranging from −455°F to 1500°F.

Manufactured as standard in stainless steel—can be made in any non-magnetic material.

Rapid response rate permits transient flow studies.

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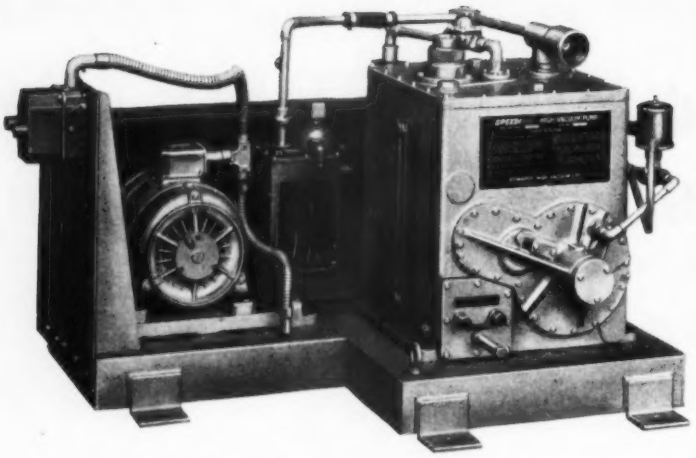

Top: " Speedivac " 1SC3000/1S50 rotary pump combination.

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" Speedivac " mechanical boosters have very high pumping speeds from atmosphere to less than 10^{-3} torr. and use no internal sealing fluid. There is no contact between the internal sealing surfaces, therefore mechanical boosters are influenced by backing pump performance. Various pumps and combinations of pumps are available to provide different performance figures.

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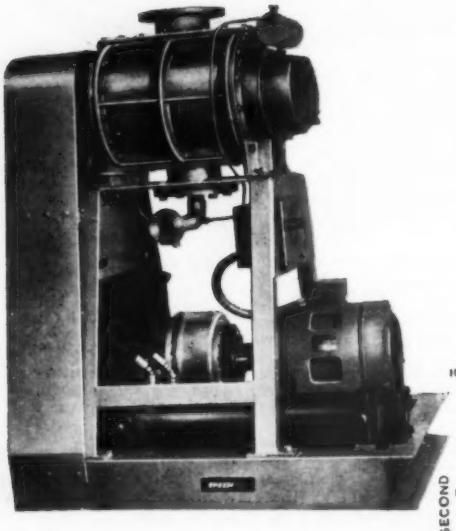
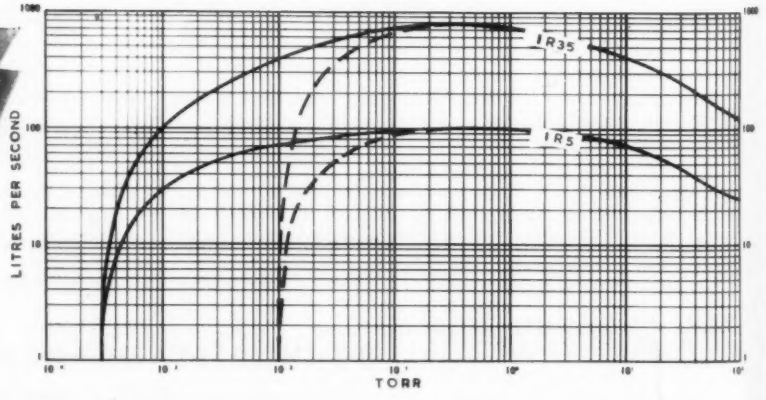


The pumping curves shown on the right indicate the performance of a 1R5 mechanical booster when backed by a 1SC900 single stage pump and the 1R35 (illustrated above) when backed by two 1SC3000 gas ballast pumps in parallel. The dotted curves indicate pump performance when operating on full gas ballast.



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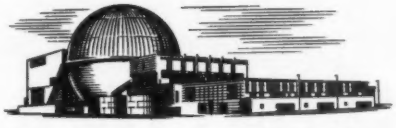

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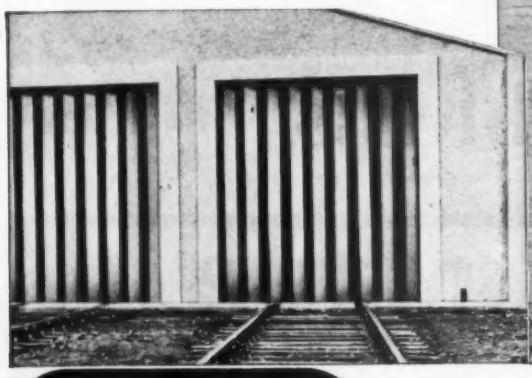

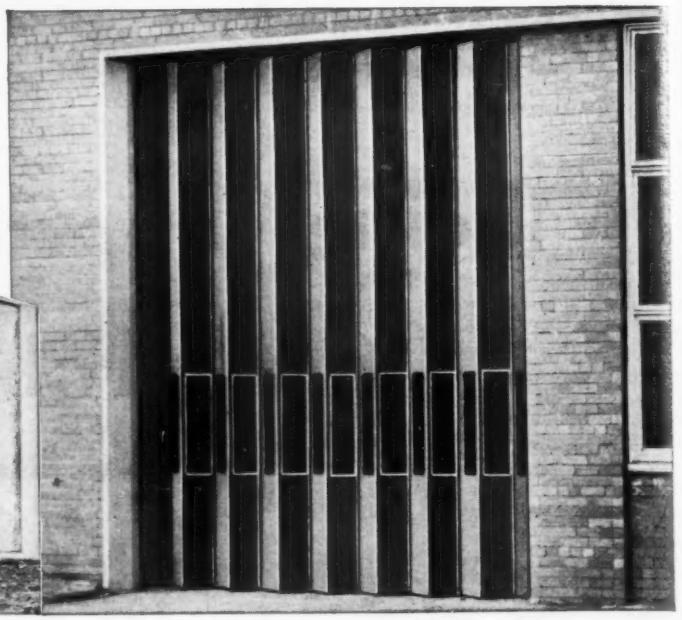

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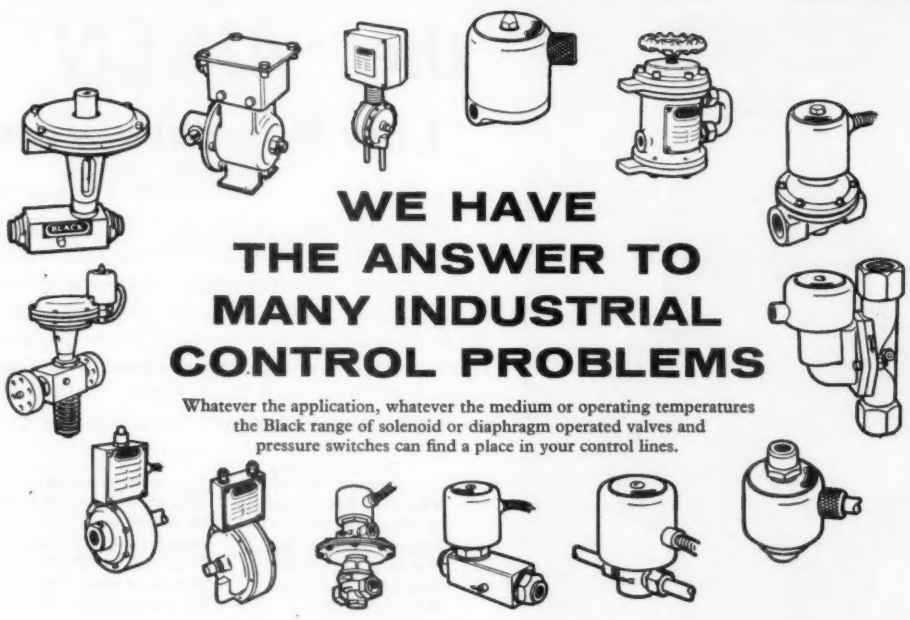

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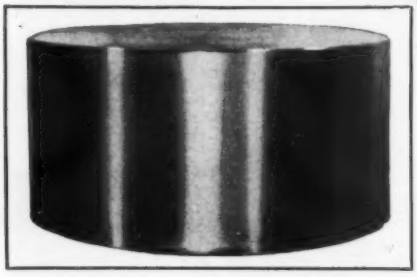

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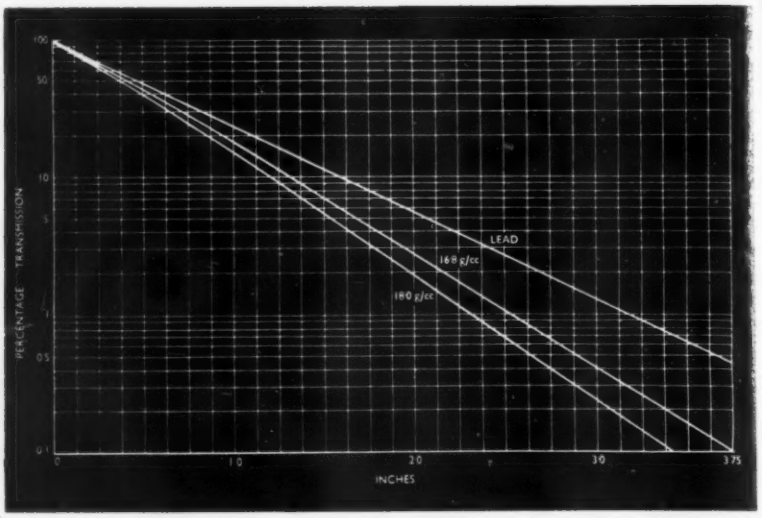

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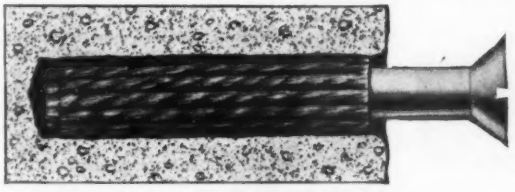

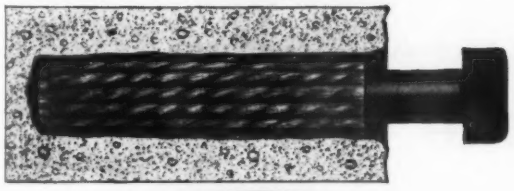

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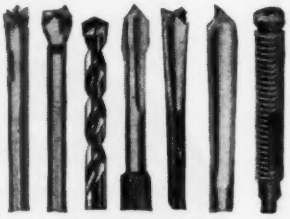

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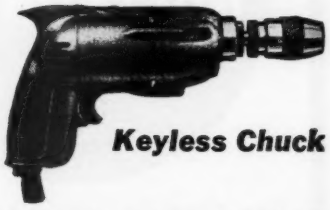

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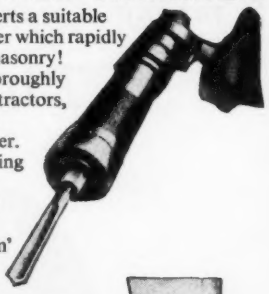

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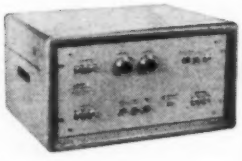

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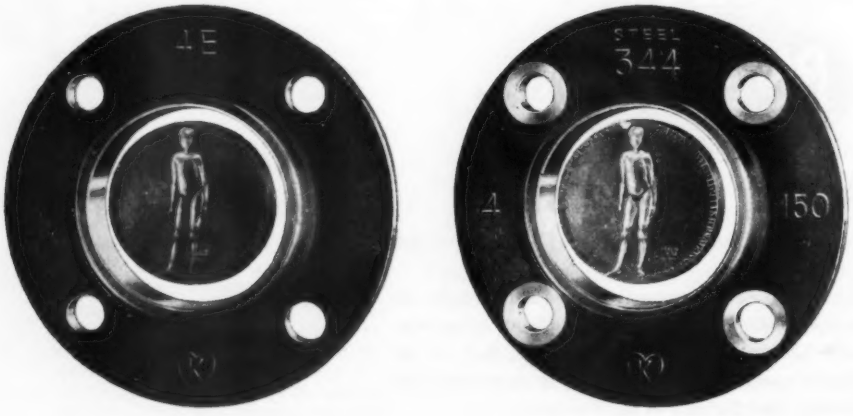

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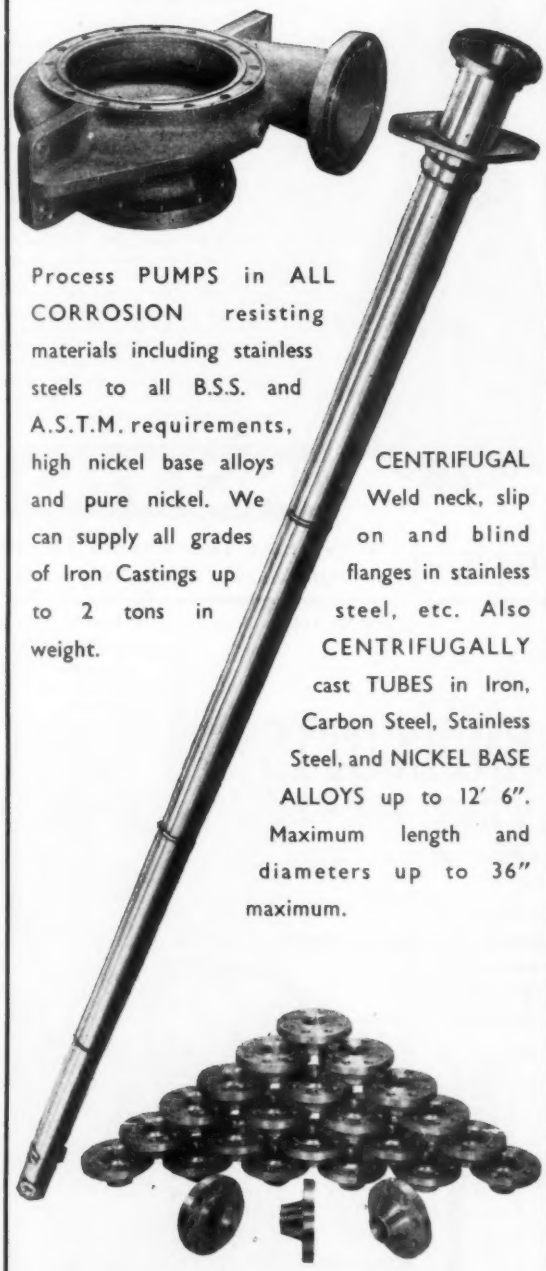

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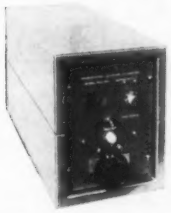

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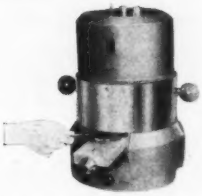

PCC-11A

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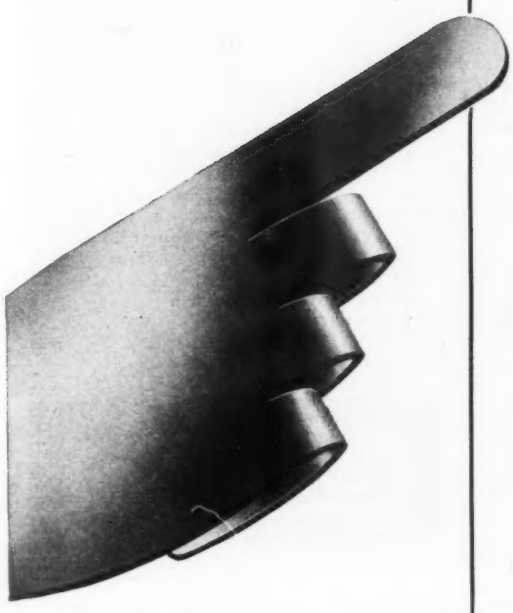

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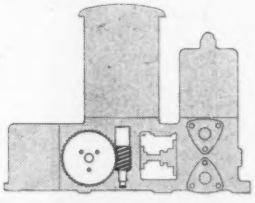

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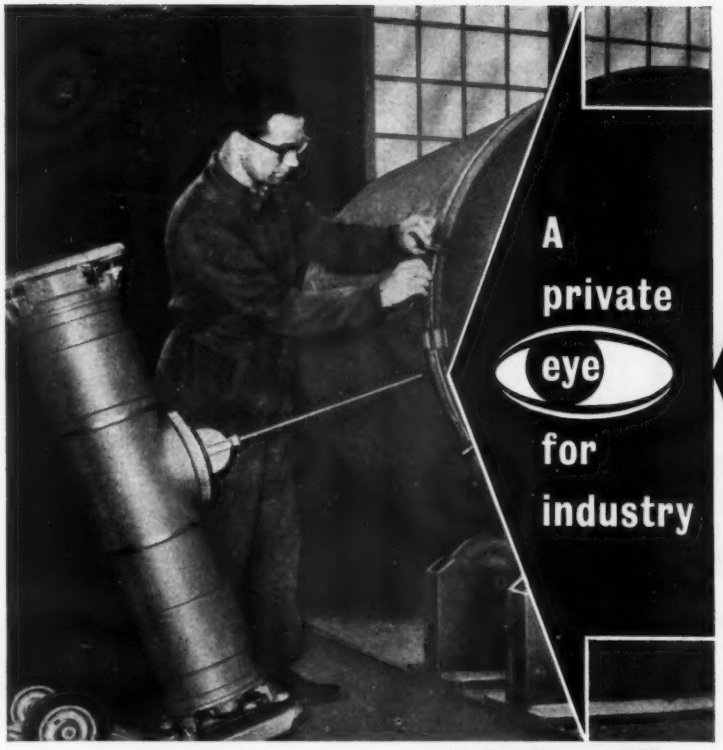

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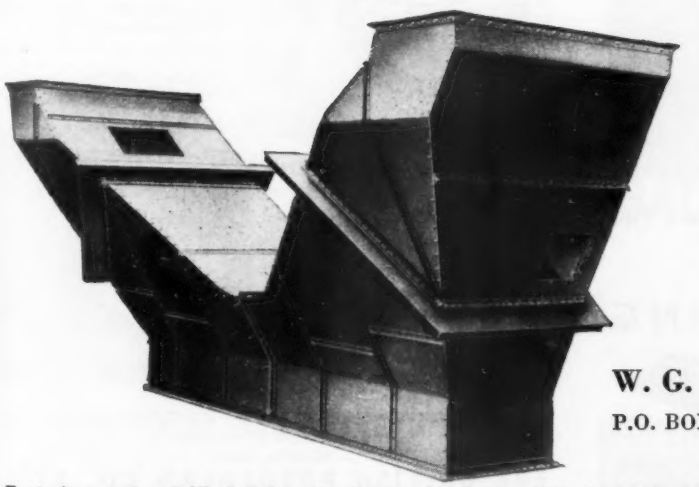

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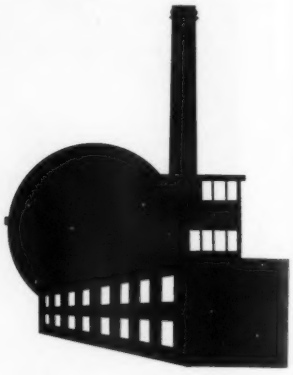

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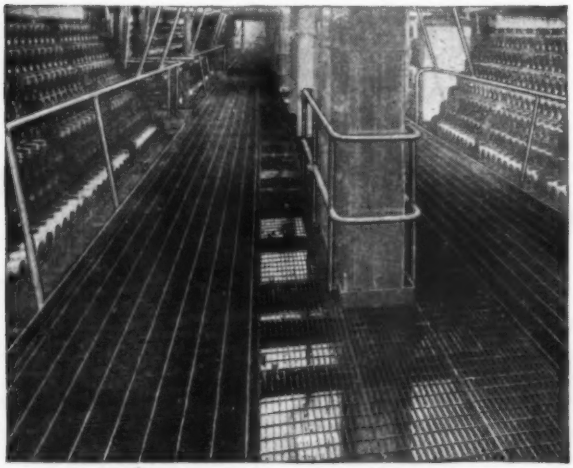

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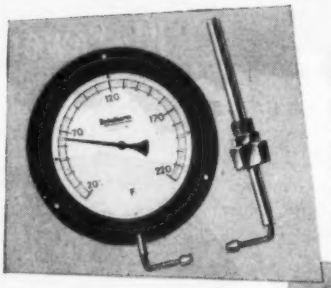

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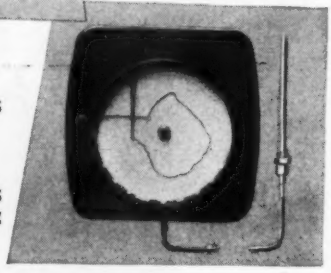

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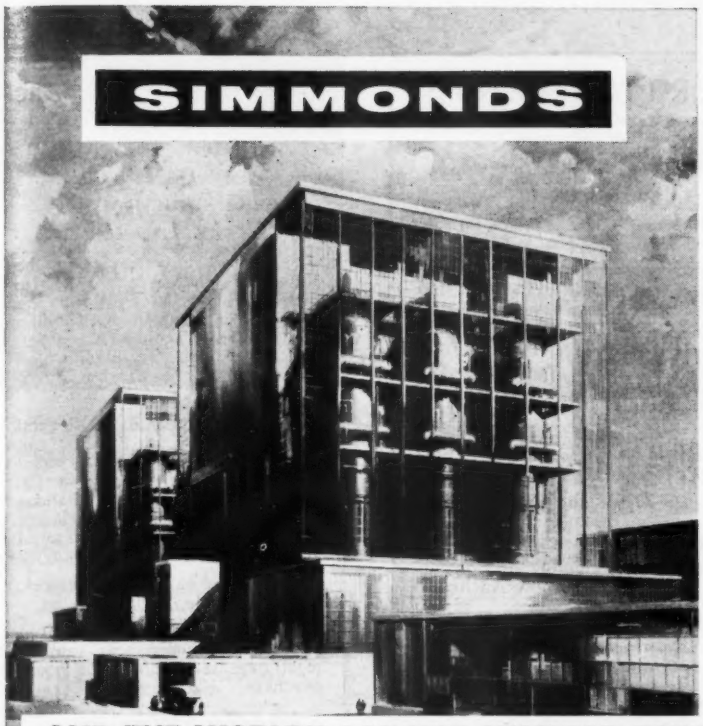

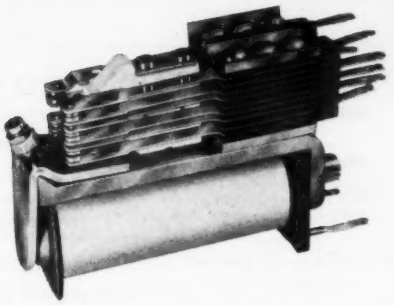

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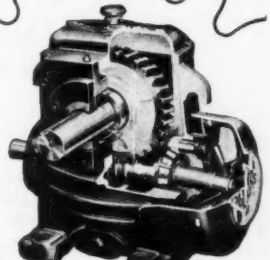

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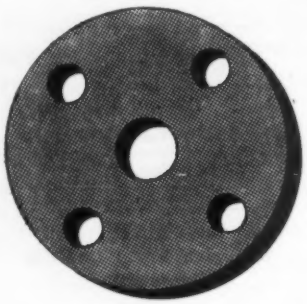

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Widnes Foundry & Eng. Co. Ltd. 113
Wiggin & Co. Ltd., Henry 109
Williams & James (Engineers) Ltd. 128

TNPG

A partnership has been established between The Nuclear Power Plant Company Limited and AEI—John Thompson Nuclear Energy Company Limited to design and construct better and cheaper nuclear power stations

This new enterprise is called

The Nuclear Power Group

and combines the research development, manufacturing and construction resources of these industrial concerns of world-wide renown.

ASSOCIATED ELECTRICAL INDUSTRIES LIMITED

CLARKE, CHAPMAN AND COMPANY LIMITED

ALEX. FINDLAY AND COMPANY LIMITED

HEAD, WRIGHTSON AND COMPANY LIMITED

SIR ROBERT McALPINE AND SONS LIMITED

C. A. PARSONS AND COMPANY LIMITED

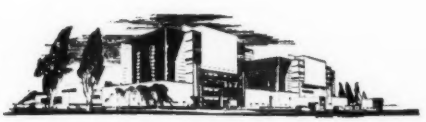
A. REYROLLE AND COMPANY LIMITED

STRACHAN AND HENSHAW LIMITED

JOHN THOMPSON LIMITED

WHESSOE LIMITED

RADBROKE HALL · KNUTSFORD · CHESHIRE



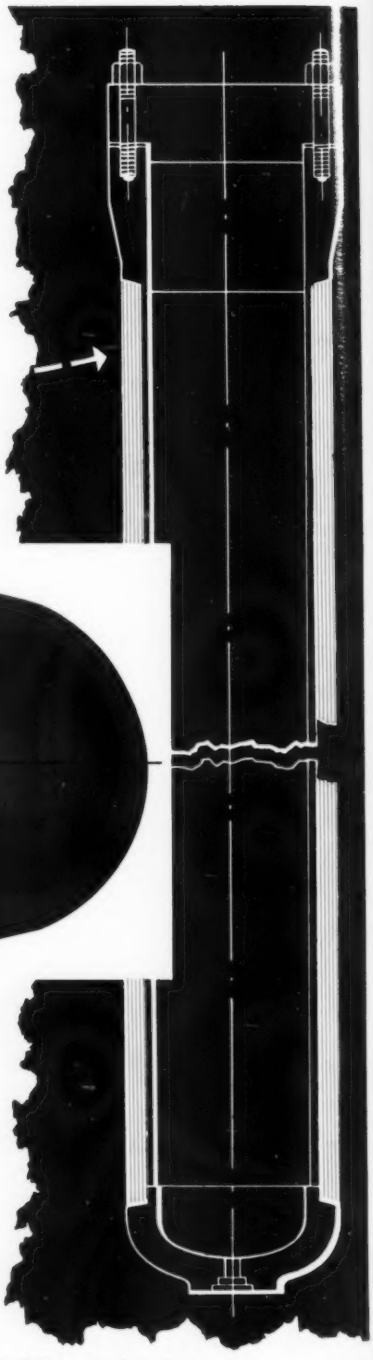
TGA No 15 B

Circle **No 206** on reply card for further details

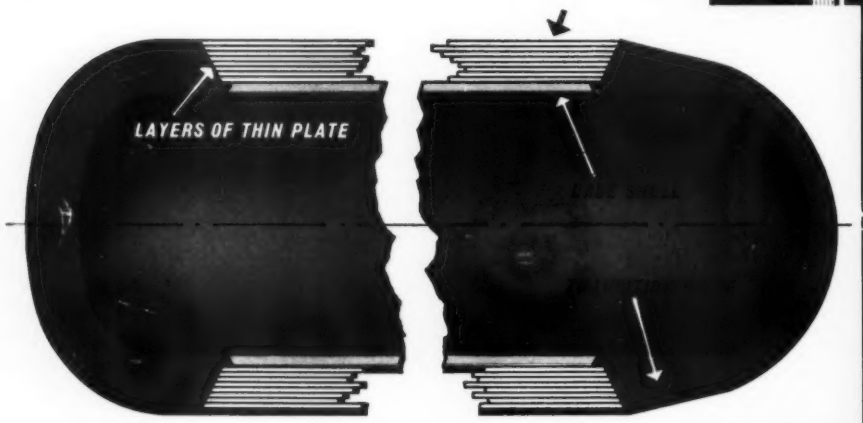
Circle No 207 on reply card for further details

Another JOHN THOMPSON development!

LAYERED
Pressure Vessels



FOR HIGH PRESSURES USED IN CHEMICAL & PETROLEUM PLANT



- **Cylindrical vessels can be made as large as you like**
- **Pressures of 5000 psi and higher**
- **Ease of fabrication permits wide range of shapes**
- **No very thick cylindrical shells to be welded**
- **Relatively thin shells give important ductile qualities**

This John Thompson development gives a new freedom to designers; a relatively thin inner cylindrical shell is reinforced by multilayers of thin plate surrounding the cylindrical section of the vessel. These layers carry both the hoop stresses and the longitudinal stresses. The ends are hemispherical or dished as required.

In this way the difficulties inherent in designing and fabricating cylindrical shells in very thick plate are overcome and it is not necessary to have recourse to expensive alternative spherical designs.

The techniques of this method of fabricating have been fully worked out by John Thompson and open up entirely new possibilities for the economical construction of very large high-pressure vessels for chemical and nuclear projects. The method also offers freedom in design for vessels not of the largest size but needing to operate at very high pressures.

WVP/8

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